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WINGS FOR TRANSPORTATION.*

(RECENT DEVELOPMENTS IN AIR TRANSPORTATION EQUIPMENT)

BY

THEODORE P. WRIGHT, D.Sc.,

Vice President and Director of Engineering, Curtiss-Wright Corp.

During the past few years, we have been forced to think of the airplane's future more in terms of "air power" than "air transport." Starting with Munich, "air power" assumed a dominant role in international affairs. It is fortunate that we, in this country, have been able to maintain a better balance between military and commercial aviation so that we can continue to appreciate that the ultimate role of the airplane is to serve peaceful purposes.

It is not intended to imply that we can, for an instant, relax our efforts in building up our air force; we cannot play the role of the lamb in a world of wolves. But in spite of this necessity for military aviation to receive such great attention, it is still essential to look into the future and study the possibilities and objectives of air transportation. This is important now and will be more so after the present conflict is ended.

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

TRANSPORTATION.

"The very pace of life depends upon the speed with which matter can be converted into energy available for transportation." Let us consider "transportation" in general: The carrying of goods or persons from one place to another. We constantly seek to reduce the effective size of the earth and to increase the effective span of human life. Progress in this field has been marked by a succession of improvements paralleling the development of civilization itself: First by walking, "leg-power"; then by domesticated animals; by the invention of the wheel; by the application of steam and the internal combustion engine to the railroad and the automobile and the steamboat; and now finally by the airplane. In each case, ourselves or our goods move from where they are to somewhere else that we want them to be in some amount of time. It is significant that the quotient of distance over time is velocity, or speed.

What then differentiates this latest means of transportation from the others? It is true that it strikes off into a different medium, one of three dimensions, the air, but the essential difference is that it carries out the function of transportation at greater speeds. From moving under his own power at four miles an hour, man has contrived to increase his speed to forty miles an hour by automobile, to sixty-five miles an hour by rail, to two hundred miles an hour by air when travelling long distances. One may ask, is it likely that air transportation will continue to advance and augment its services, even to become the major means of transportation? To do this it must be economically sound; and the year just ended shows that progress has reached a stage of advance where this is now the case.

We wish to see where we are going in this new field. Trends are therefore important and it is a major object of this paper to discuss this item of trends, alluding to some of the engineering methods that have been used in order to reach our present status, and to others which will be used in order further to improve. Finally we ask: Should it be? Is it in general good for man to be able to travel from place to place three or four times as rapidly as was heretofore possible? Will his life be fuller and richer and will there be greater

happiness for a greater number if this maintains? My answer to all of these questions is "Yes," as in the final analysis, the destiny of the airplane will be to serve peaceful rather than warlike purposes. But the attainment of such objective will not be automatic. We cannot be too certain. We must constantly bear in mind the social implications of science, and make sure that civilization is advanced and not retarded by our scientific progress, particularly by its most recent acquisition, the airplane.

HISTORY.

With this brief statement of the case, let us now examine more particularly the history of air transportation. In a lecture given by Mr. E. P. Warner at Norwich University on this subject, he selects as a starting point the year 1870, and I will follow his example.

The Franco-Prussian War was under way and the city of Paris was being besieged. Normal communication with the outside provinces was completely cut off. The Parisians finally resorted to the use of the free balloon to remedy this situation. During the one hundred and twenty-seven days of siege, sixty-four balloons were sent up from Paris, carrying some four million letters and eighty-eight passengers to the outside world. Only a few of the balloons were lost, either at sea or to the enemy, so that this initial effort in air transportation may be considered to have been successful. This means could be used, of course, only for transportation out of Paris, but an ingenious method was devised for making possible the despatch of return communications. Each balloon carried a quota of homing pigeons when it left Paris which were subsequently released with reply messages.

The next step in aerial transportation took place in 1911, also using lighter-than-air-craft. A service utilizing five Zeppelins was operated for two years between several cities in Germany. During this time, over thirty-four thousand passengers were carried, travelling one hundred and seven thousand miles in all with no loss of life. The service was far from satisfactory economically and was abandoned.

But we are interested primarily in heavier-than-air-craft. The epoch-making flight of the Wright Brothers in 1903 was

followed by nine or ten years of activity which involved flying, but not air transportation. Aviation "meets" consisting of much stunt and demonstration flying were the rule.

Almost from the first, however, the prospect of carrying mail by air was in the minds of all these enthusiasts though it was not until the end of this period of "infancy" that any official carriage of mail by air took place. Preceded by "stunt" mail-carrying wherein a small amount of mail might be transported to a flying field by auto truck, flown about a bit, perhaps to another field, and then picked up by another (or possibly the same) truck and carried back to the same post office, a real start was made on September 23, 1911, when the Post Office Department authorized Earle Ovington to make an official mail flight. Emphasis must here be placed on the fact that at that time it was the carrying of mail that appealed to the popular fancy as the goal of the airplane.

Several isolated attempts at starting air transport lines took place following this period, such as one in 1914 which operated with a single flying boat between St. Petersburgh and Tampa, in Florida, a distance of thirty-six miles. All of these efforts, essentially uneconomical, were abandoned after short periods of operation. Greater airplane efficiency had to be realized before success could be attained.

A real start, however, was made in 1918 when the Post Office Department decided to fly the mail between New York and Washington, D. C. The Army Air Service, with Major Reuben Fleet in charge of the operation, was designated to do the job since initial bids for airplanes designed especially for the service resulted in delivery dates for the craft which were unsatisfactory to the impatient officials. The first flight was made on May 15, 1918, and was intended to consist of a trip in each direction. The flight of the plane leaving Washington, with the take-off witnessed by the President of the U. S. and members of his cabinet, terminated shortly thereafter in southern Maryland, completely off the course. The trip from New York, however, was successful, consuming three and one-third hours' time at a cost, in this Army Training Plane, of approximately the same amount per mile as is now required to fly a modern fourteen passenger

transport with many times the load and speed. However, the line continued and great credit is due this pioneering effort to carry the mail regularly by air, a service which has never ceased to improve and expand.

Landmarks in this expansion followed in rapid succession. One was the opening of the New York-to-Chicago route in 1919, using re-built war-time DH-4 airplanes. Another, and an illuminating vision of the future, was the first crossing of the Atlantic Ocean by air—the successful undertaking of the U. S. Navy, using NC-4 Flying Boat.

On September 8, 1920, the first transcontinental flight was made during a competition, one plane getting through in nine days four and one-half hours. But an event of outstanding importance occurred on February 22, 1921, when Jack Knight completed a night flight from Omaha to Chicago, under terrifically unfavorable weather conditions. His way was lighted only by occasional bonfires. Lighting of this sort at frequent intervals had been promised but because of weather conditions so unfavorable to flying, many communities failed to light their fires. Made possible by this night flight, mail was carried from San Francisco to New York in about thirty-three and one-half hours, approximately twice the time now required for a similar service.

Another important event of 1921 was the inauguration by the Army Air Service of a regular Dayton-to-Columbus airway for night flying. Here the revolving beacon with periodic flashes was developed, an innovation which was to prove so advantageous in the system of airways later evolved for this country. Its inherent advantages over the simple lighthouse type favored in Europe contributed much towards the more rapid advance of air transportation in this country. The lighted airway from Cheyenne-to-Chicago was completed and put into operation on July 1, 1921. This was a most important step in progress as by it a great number of enthusiasts of that time appreciated anew the fact that in order to take full advantage of the airplane as a means of transportation, night flying must be used. This country surpassed Europe by a wide margin both in the proportion and technique of night flying operations.

By 1927, the Post Office Department had satisfactorily

established its basic air mail system and was ready to turn it over to private operators. The last flight by the Department was on September 1, 1927. It had expended seventeen million dollars in its pioneering efforts, had received back about seven million and thus gave to the American people a magnificent start in air transportation at the exceedingly small relative net cost to the taxpayers of ten million dollars. The operation had been dangerous and had resulted in many fatalities, as must all pioneering efforts, but the fatality rate decreased sharply from its inception to the final flight at which time it was at least ten times as safely conducted as at first.

Having outlined the progress in carrying the mail which was the first use to which the airplane was put in commerce, let us now consider the progress in carrying passengers. As remarked above, at first passenger carrying did not strike the American public fancy as the final role of air transport. This differed from the attitude in Europe where passenger-carrying rather than mail-carrying seemed to be the goal, and consequently where the start in air transportation was made. However, there were a few lines in the United States, the primary purpose of which was to carry passengers. These were started in 1919 and operated between New York and Atlantic City; Miami and Nassau; Seattle and Victoria; and, Key West and Havana. It is noteworthy that they all used flying boats and that although some useful service was given, they were not by any means successful financially.

In 1920, the Army Air Service again made a distinct contribution when it inaugurated its model airways system. Captain Burdette S. Wright initially supervised the operation which lasted through the next five years, involving a total of three hundred and thirty-six thousand miles of flying. Aside from the contribution made in requirements of cross-country flying for Army officers, a real lasting service was provided air transportation by spreading air-mindedness to hundreds of communities along the airways. This resulted in a period of airport development of great importance.

The relationship between government and private enterprise in developing air transport was very unsatisfactory at this time. Recognizing this, a group known as the Morrow

Board was appointed by the President to investigate the situation. A very statesmanlike report was made, resulting in the passage of the Air Commerce Act on May 20, 1926, a date to be noted as an important landmark in air transportation development in this country. An Assistant Secretary of Commerce for Air was appointed and steps were taken for regulating air transportation for the future. Then, in 1927, came the solo trans-Atlantic Flight of Colonel Lindbergh which set the country aflame with enthusiasm for the air. Expansion followed at once with such lines as National Air Transport, Transcontinental Air Transport, the Aviation Corporation network (later American Airways), United Aircraft and Transportation Corporation, and Western Air Express, organized and started in operations by 1929.

Another development of far-reaching significance was the inauguration of the Pan American Airways System which started in 1927 with a run of ninety miles from Key West to Havana. This line expanded rapidly to twelve thousand miles in 1928, encircling the Carribean and then to South America in 1930, further extending its mileage to thirty thousand. We all know and are proud of the more recent developments of Pan American Airways wherein the Pacific was spanned in 1935, bringing the total mileage to thirty-three thousand, and the Atlantic in 1938 raising the figure to fifty-four thousand miles, a truly remarkable development and one envied by all the countries of the world. Pan American has furnished a most important service to our country in extending communication services to the far flung points on its routes. In the future, this dual role, transportation and communications, will be important in international affairs.

But to return to a somewhat earlier period, we find that by 1931 there had been completed the phase of mergers which sought to combine the great number of individual airline companies previously organized, into basic groups much as we know them to-day. If aviation's "infancy" ended in 1911, we can say that its "childhood" ended in 1926 and its "adolescence" in 1931.

One of the first airlines to be formed in Europe was K.L.M. in 1920. Its record of expansion and achievement has made it one of the greatest lines in the world. We, in this country,

are rather proud of the fact that the equipment which it has used during the last five or six years has been of American design and manufacture—Douglas planes with Wright engines. Imperial Airways was formed in 1924, Lufthansa in 1926, and Air France in 1933. Perhaps the most significant difference between foreign airlines and our own is in the matter of subsidies. In the first place, the amount of subsidy abroad was and is larger than ours; and in the second place, the subsidy has usually taken the form of direct payment to the airlines as against the American way of payment for carrying the mails. In addition to the far smaller proportion which the subsidies of our airlines bear to income from other sources than maintains abroad, the method of determining it, as mentioned above, is of equal importance in inducing American airlines to make themselves self-sustaining economically. This is certainly the ultimate goal and its attainment is much more nearly approximated here than abroad. It is so much the case that many doubt the correctness of calling air mail payments here a subsidy as they seem really to represent a legitimate government expense in providing a most necessary service.

This very brief history of air transportation can be concluded by stating that after 1931, which ended the period I called "adolescence," wherein its own development was its chief concern, the industry started its next period of "young manhood." Its strength was by then such that from the standpoint of competition it could force consideration on other forms of transportation. Let us therefore consider the broad relationship between air transportation and transportation by rail.

AIR TRANSPORT IN COMPETITION WITH OTHER TRANSPORT METHODS.

In the first Table, Fig. 1, this comparison shows that by virtue of greater speed and shorter distances, the time-saving factor favors the air by about three and one-half to one. The fare differential favors travel by rail by a ratio of three to two, but combining the two in a time-cost efficiency factor, there appears a resultant gain for the air by two and one-half to one. A more refined analysis is given later but because of the existence of these broad considerations, the rapid expan-

FIG. 1.

Transportation.

Rail vs. Air.

	Variation.	Average.
Speed Between Stations Over 200 Miles Apart.....	.30 to .40 : 1	.33 : 1
Distance Between Stations Over 200 Miles Apart..	1.05 to 1.22 : 1	1.15 : 1
Time Between Stations Over 200 Miles Apart.....	3.00 to 3.90 : 1	3.50 : 1
Fare * Between Stations Over 200 Miles Apart....	.65 to .70 : 1	.66 : 1
Time-Cost Efficiency Factor = 1/Cost Factor × Time Factor.....	.30 to .49 : 1	.434 : 1

sion of air transport has resulted. Let us now view this progress in terms of equipment.

EQUIPMENT USED IN AIR TRANSPORTATION.

Starting from the use of Army Training Planes during World War I and later modified Army Observation Planes, it

FIG. 2.

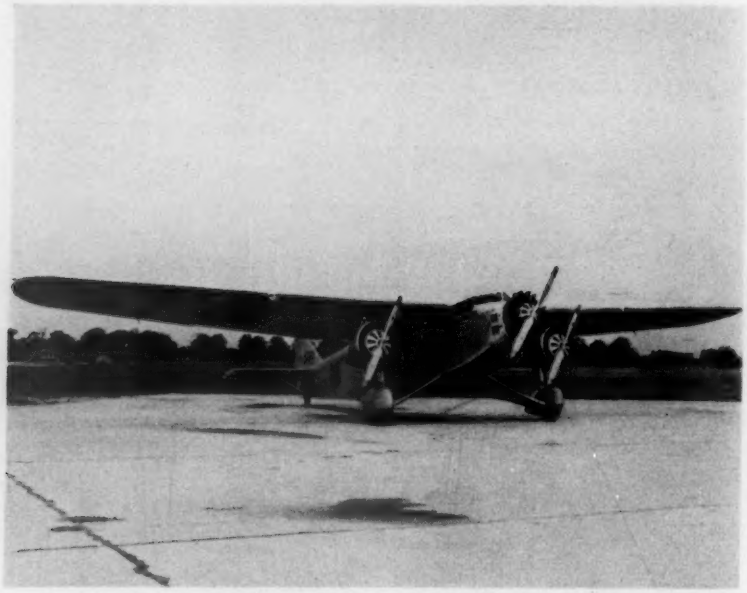
Boeing 40B, 1926.

was not until 1926 that types designed specifically for air transport use appeared. As an example of this early effort, Fig. 2 illustrates the Boeing Model 40, a biplane designed

* Fares cited are based on quotations for one-way trips, including Pullman fares in the case of rail travel, and not taking account of reductions for round trips, for use of scrip tickets or excursion rates, or other special considerations, such as the saving in expense for meals when travelling by air. The result of combining such factors will react to the advantage of air travellers, giving, in round numbers, a Time-Cost Efficiency Factor favorable to the air when comparing to rail of about 2.5 : 1.

much along the Army Observation Plane formula but nevertheless specifically built for air transport. Its cruising speed was about one hundred miles an hour. By 1929, the Ford Tri-Motor had come into use for air transportation at a cruising speed of about one hundred and five miles an hour (Fig. 3). The expansion of the airlines at this time and the period immediately following was very largely based on the

FIG. 3.



Ford tri-motor.

Ford which appealed to the popular fancy, because of its monoplane arrangement, its all-metal construction, and its three engines. Not economical to operate in the light of present standards, it nevertheless seemed to operators of those days the last word in efficiency and many considered that nothing better need be expected. It was noisy, it was none too comfortable, but, after a fashion, it did the job.

The Curtiss "Condor" (Fig. 4) appeared in 1930. Although a biplane in accord with the earlier traditions, it

nevertheless marked a distinct advance in two respects. First, it had two engines and would actually fly at a reasonable altitude in a satisfactory manner when one engine was inoperative. Secondly, it made a very distinct contribution towards comfort for passengers, both from the standpoint of the luxurious seats which it provided and, more particularly, because of the installation of sound-deadening means which reduced the cabin noise level to a point approximating that

FIG. 4.

Curtiss "Condor," 1930.

of other means of transportation. It had a cruising speed of one hundred and sixteen miles an hour.

In Europe at about this time there appeared the Handley-Page "Hannibal" (Fig. 5), a biplane type equipped with four engines but cruising at under one hundred miles an hour. A fair degree of comfort was provided but its slow cruising speed would not seem to justify the long period of service that it had on Imperial Airways.

A sesqui-plane, the French Breguet Model 39, was developed in 1934 and the German Junkers Triplane came out

that same year. Like the Ford, this latter was all-metal construction and had three engines, but unlike the Ford, it had a low wing rather than high wing arrangement.

FIG. 5.

Handley-Page 42, 1931.

FIG. 6.

Boeing 247—1934.

In this country, the next plane which should have special mention was the Boeing 247 (Fig. 6) also appearing in 1934. Cruising speeds were raised to one hundred and eighty miles per hour by this ship which also had most of the present day features of form, including all-metal low wing twin engine monoplane construction with retractable landing gear. This type is still giving good service on several airlines. In 1934, there also appeared another version of the Curtiss "Condor," the chief contribution of which was the introduction of the sleeper arrangement for night flying. Figure 7 illustrates the interior of this ship alternatively arranged for use during the

FIG. 7.

Curtiss "Condor," sleeper version, 1934.

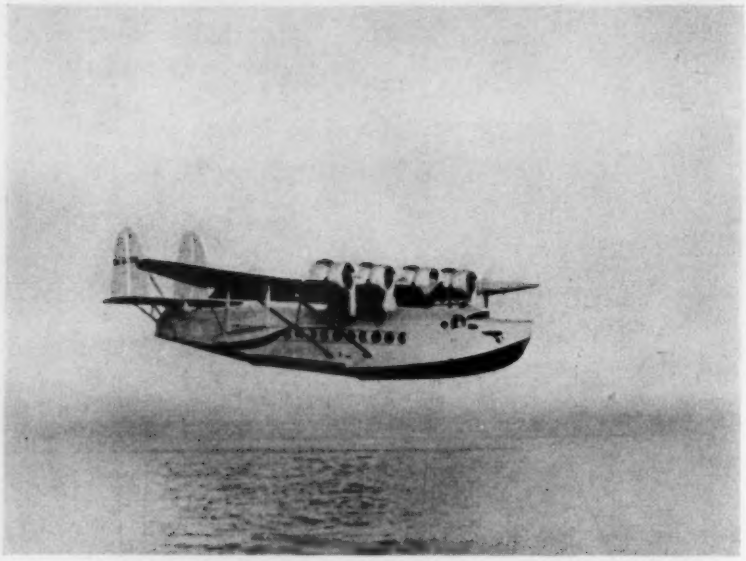
day and at night. With planes of this type American Airlines started its popular cross-country sleeper schedules.

As to flying boats: A step ahead occurred when the Sikorsky S-42 was placed in service on Pan American Airways. Although the first large boat used by that company was the Consolidated "Commodore," nevertheless, the S-42 and S-42A were and still are standard equipment for the South American runs. Figure 8 shows this Sikorsky.

It was also in 1934 that the Douglas DC-2 appeared, embodying all of the essential improvements which are used in the present day air transport. In addition to the use of two engines low wing all-metal monoplane arrangement with retractable landing gear, introduced by Boeing, it also incorporated the Wright Cyclone Engine with NACA cowl, the

wing flap with resultant permissible increase in wing loading, and the controllable pitch propeller. Cruising at one hundred and eighty miles an hour with a complement of fourteen passengers, it provided a degree of excellence in air transportation unequalled (if not indeed unapproached) by any other piece of equipment. It is indeed fitting that the Guggenheim Medal should be awarded to Donald Douglas

FIG. 8.



Sikorsky S-42, 1934.

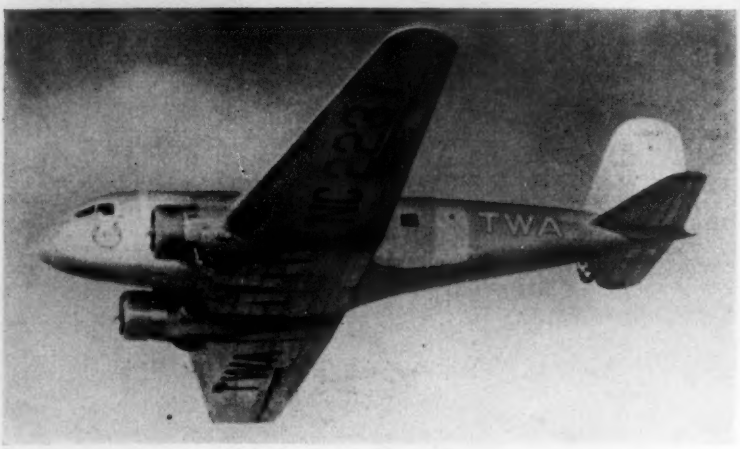
this year in recognition of his contributions to air transportation, starting as they did mainly with the introduction of the DC-2. Figure 9 is a view of this airplane in flight.

Again to revert to flying boats, there is shown in Fig. 10, the Martin 130, by means of which the Pacific route of Pan American Airways was opened up. Cruising at one hundred and thirty miles an hour, this flying boat possessed a very high ratio of useful load in proportion to gross weight.

The next big step in equipment development was the Douglas DC-3, the present standard of air transport equip-

ment of the airlines of the world. Although developed directly from the DC-2, nevertheless, by virtue of greater span and larger fuselage, coupled with slightly more power per-

FIG. 9.



Douglas DC-2, 1934.

mitting a substantial increase in useful load, it has made possible very great economy of operation. With a gross weight of about twenty-four thousand pounds and a payload

FIG. 10.

Martin 130, 1935.

of five thousand, it cruises at one hundred and eighty-one miles an hour and can be operated at a direct operating cost of sixty-five dollars an hour; thirty-nine cents a mile; and 1.8

cents per two hundred pound payload unit, per mile. This airplane is shown in Fig. 11.

FIG. 11.

Douglas DC-3, 1936.

TRENDS.

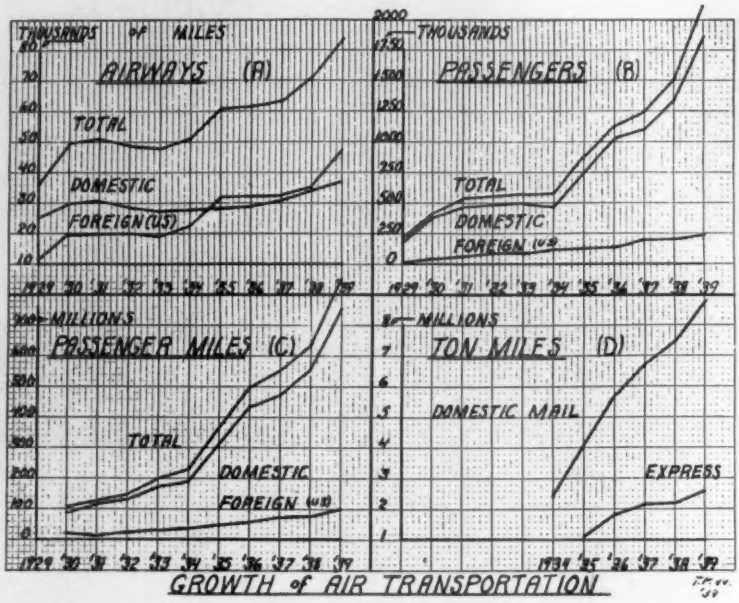
Having illustrated the advance in air transport equipment to this point, it is desirable now to show by a series of graphs the trends which are indicated for various phases of our subject.

GROWTH OF AIR TRANSPORTATION.

First, let us consider the growth of air transportation as illustrated in Fig. 12. The four sets of curves are self-explanatory in showing a tendency to accelerate in growth during the past two or three years, and particularly in 1939, as measured by growth in airways, passengers, passenger miles, and ton-miles of mail and express. One can only reach the conclusion from these data that there will be a

substantial period of time before any falling off in tendency to increase may be expected.

FIG. 12.



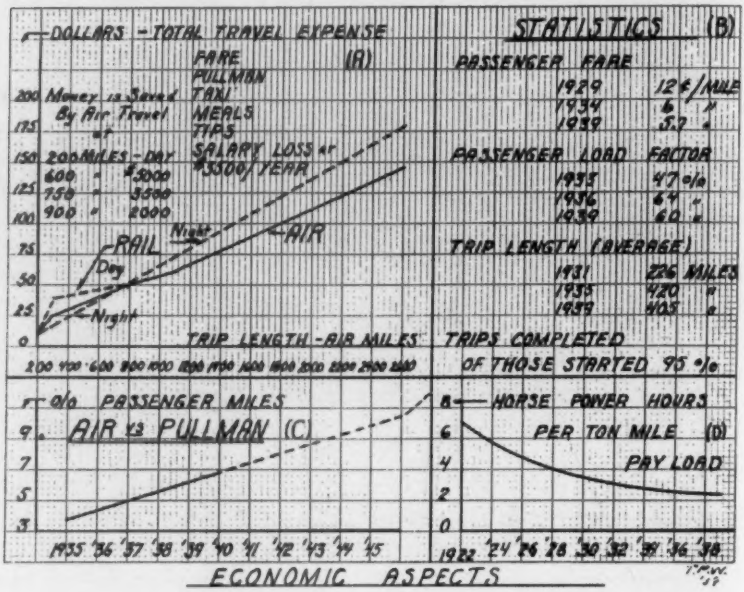
ECONOMIC ASPECTS.

Now let us consider certain economic aspects of the situation in a second group of graphs (Fig. 13). Here, under 13(*A*) is indicated the saving involved by air travel as against rail when considering all factors of expense including salary loss, and under three classifications. For the middle case, a salary of $3500 per year, it appears to be economical to travel by air if the distance involved is 750 miles or greater, and under the assumption that the alternative of rail travel would be carried out at night to cut down the salary loss while travelling, to nothing or to a minimum. If travel were to be carried out in the daytime by either means of transportation, the lines representing air and rail travel cross at about two hundred miles for all salary brackets.

Under 13(*B*) a few statistics are shown. Reduction in passenger fare from twelve cents a mile to 5.7 cents has

brought this item to a point where from graph 13(*A*), it appears reasonable travel economy is effected. The tendency for passenger load factor to stabilize at sixty per cent. requires some comment as, offhand, it might be considered that a larger amount would be necessary or at least desirable. However, it should be realized that in order to attain this average, there must, of necessity, be many trips which are one hundred per cent. filled. It is also evident that at one

FIG. 13.



hundred per cent. load factor, it would be likely that in many cases, passengers would be turned away because of lack of capacity. Furthermore, such a lack of capacity would imply failure on the part of the operators to render a service which can reasonably be expected by the public. It appears that the tendency to stabilize at sixty per cent. will persist and that airlines must therefore reckon on making their operations satisfactory to themselves financially on this basis.

The next noteworthy item is average trip length which is apparently stabilizing at about four hundred miles, a decrease

from a few years ago due to a tendency recently for short haul traffic to increase. Next, there is the figure of ninety-five per cent. efficiency in completing trips of those started.

In 13(*C*) there is shown the increase in air traffic against Pullman traffic from a figure of just over three per cent. in 1935 to almost seven per cent. at the present time. As the points on which this curve are based lie on a straight line, it is reasonable to expect continuation of this tendency, reaching ten per cent. by 1945. It is possible that there will be an acceleration thereafter and several have prognosticated a final flattening out at forty or fifty per cent. Apropos of this possibility should be mentioned the comparison of bus and rail traffic. A comparison of these two modes of travel showed that but one per cent. as many people travelled by bus as by rail in 1920 while by 1932 a figure of thirty-seven per cent. was reached.

Trans-Atlantic air travel has only just commenced, but in view of the loads now being carried by Pan American Clippers, it can confidently be predicted that the proportion of air to first class boat travellers will be substantial. The market is available, as recent analyses have shown that in normal times there are a hundred or more passengers per day crossing the ocean in liners and who pay rates comparable to those asked by Pan American for air passage. Already Pan American, with over one hundred crossings to its credit, is averaging about twenty passengers a trip on a twice-a-week schedule with occasional schedules of thirty or forty. Mail, averaging about one ton a flight, has occasionally gone to thirty-five hundred or four thousand pounds. It is rumored that more frequent schedules will be justified in the near future in the expectation that even in peace time such frequency of schedule will be justified.

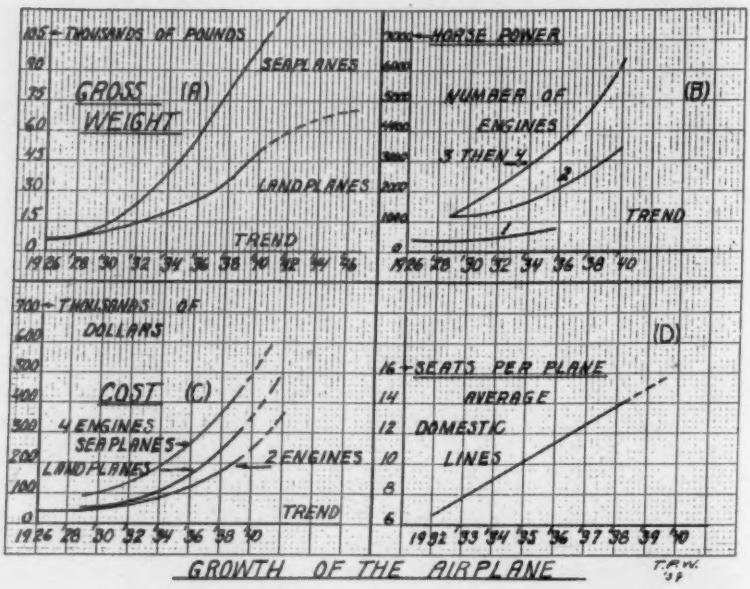
The last sub-division of Fig. 13, graph (*D*), shows the improved efficiency of the airplane as measured in terms of horsepower-hours per ton-mile-payload. This factor has decreased (showing increased efficiency) since the start in 1922 from a figure of seven to a present figure of just over two. The fact that this curve has flattened out is a clear indication that the difficulties of further improvement will be great. It should be noted, however, that in general our airlines have

made a profit in 1939. I previously mentioned a direct operating cost of 1.8 cents per passenger mile for the Douglas DC-3 airplane. If a sixty-six per cent. overhead is assumed and a sixty per cent. capacity load factor, it means there is an actual operating cost of five cents per passenger mile. Subtracted from present fare averages of 5.7, a profit of 0.7 cents per passenger mile, or just over twelve per cent. results; so passenger air transportation with present equipment can be made profitable.

GROWTH IN SIZE.

The graphs of Fig. 14 are designed to illustrate the growth of the airplane itself. It should be realized that average

FIG. 14.



curves have been drawn to show the tendency to increase in size. Naturally, there are smaller pieces of equipment coexistent with larger. In fact, curves (*A*), (*B*), (*C*) of Fig. 14 rather than being averages of all equipment are more accurately a trend of the largest sizes for any given period. The

tendency of the weight curve, 14(*A*), for landplanes to flatten out as against the non-existence of any such tendency for flying boats is significant in connection with the different type of service each provide. The long-distance service of the flying boat requires less frequency of schedule and makes it likely (as indicated in graph (*A*) of Fig. 14) that greater and greater sizes will be developed. However, for landplanes, the desire for a service "every hour on the hour" automatically sets a limit on size increase. It is perhaps noteworthy that the Douglas DC-4 airplane which will first be placed in service is not the original DC-4 but a smaller version. This flattening-out in size curve for landplanes will, of course, not persist if in the future, as may well occur, landplanes are used for trans-oceanic service.

Graphs (*B*) and (*C*) of Fig. 14 show respectively, increases in horsepower and cost of equipment. Twin-engined landplanes costing $115,000 may be expected to increase to over $225,000 and four-engined equipment in the $350,000 bracket will be with us soon. In the flying boat field, we are now in the half million dollar class. Graph (*D*) of Fig. 14 shows the steady increase in average seating capacity, rising from seven in 1932 to fourteen at the present time.

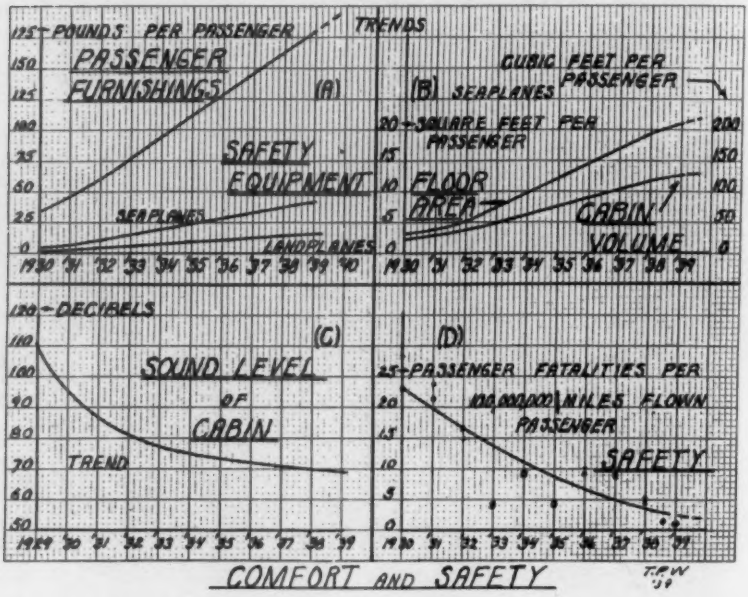
COMFORT AND SAFETY.

The curves of Fig. 15 are presented to show improvements in comfort and safety.* Graph 15(*A*) is extremely important, in that the steady increase in weight per passenger of passenger furnishings and safety equipment shown has been so marked in the past ten years that we have arrived at the point where the operator now carries the equivalent weight of two passengers and baggage for every one that he actually carries! In other words, passenger furnishings now amount in weight to one hundred and seventy-five pounds per passenger with safety equipment at about fifteen pounds. This increase of one hundred and fifty pounds per passenger of such equipment between the old Ford and the Douglas DC-3 is a good measure of the improvement in comfort of the modern airliner. An interesting side comment here concerns the fact that because

* I am indebted to Mr. E. T. Allen for the data necessary to plot curves *A* and *B* and in one or two of the other curves shown.

of the increase just described, it has not been possible to increase the useful load in terms of percentage of gross load. In fact, an actual decrease has occurred. From 1929 to the present time, this percentage has decreased from forty to thirty-three where it appears to be stabilized. For flying boats, during the same period, it started at forty-five per cent. and increased in certain instances to fifty but now seems to be stabilizing at forty-two. The fact that it has not gone

FIG. 15.



down still further is only due to improvements in structural efficiency which have been accomplished.

Provision for increased space as shown in graph 15(*B*) will be recognized at once as a substantial contribution towards passenger comfort. These curves for flying boats give values roughly twice those that maintain for landplanes. For the latter, our modern transport planes provide over ten square feet and sixty cubic feet per passenger. But from the standpoint of comfort, it is perhaps Fig. 15(*C*) which shows the most important contribution, namely, reduction of noise.

The decibel unit (old scale) is used and it may be seen that from the days of the Ford in which noise of one hundred and ten decibels existed, we are now in the seventy decibel range. This forty per cent. decrease is (as mentioned above) based on the decibel unit which, in turn, is a logarithmic scale measurement. The actual sound in our present day air transport cabins is but one-fifty thousandths as much as ten years ago! In fact, it is almost exactly the same as for the Pullman car, being of course, far less than in street cars and subway trains, and only slightly more than for an automobile travelling at fifty miles an hour. To obtain further improvement will require expenditure of a greater amount of weight and it is likely that a final stabilizing figure of sixty-five, or possibly slightly less, will maintain.

And now for safety (Fig. 15(*D*)). Here have been shown the actual points for each year which have maintained during the past ten years for passenger fatalities per one hundred million passenger miles flown, and a trend curve. The record is remarkable and important. Let us take the year 1938 where the figure is five and let us appreciate that this figure represents one fatality for twenty million passenger miles, which is the equivalent of a flight each day from New York to Los Angeles and back the next day, carried on without interruption for twenty-one years. The record for 1939 is very substantially better (an actual figure of less than $1\frac{1}{4}$!), so much so that President Roosevelt issued a special news release on this record on November 7 by which date five hundred million passenger miles of air transport operations had been completed without a fatality and which, as he dramatically pointed out, was the equivalent of transporting the whole population of the City of Washington to Boston and back. This record has continued unblemished, approaching two-thirds of a billion passenger miles now, and unstinted credit is due airline operators for the infinite number of details earnestly carried out which brought about this fine condition.

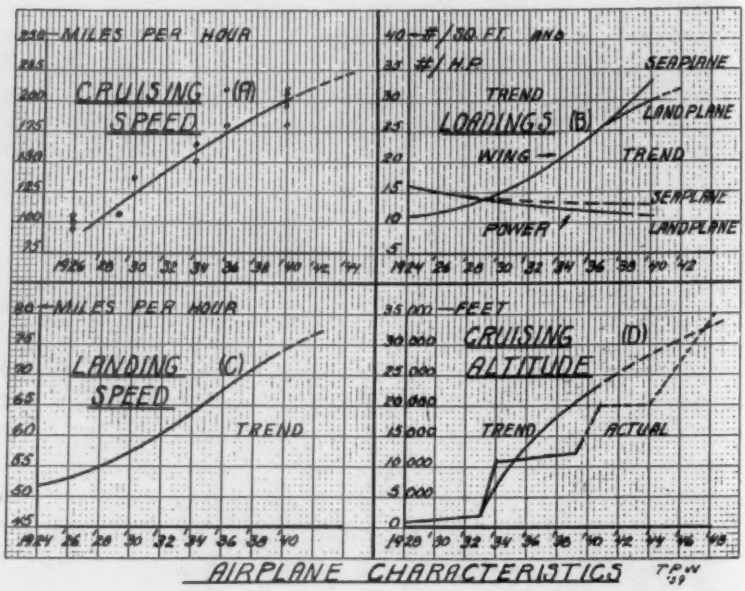
Substantial contributions have also been made by our plane and engine designers in the airplane itself to help make this record possible. A few of these are: The use of multi-engined equipment having satisfactory flying qualities under all conditions of flight; the general improvement in stability

and controllability; the improvement in reliability of the powerplant; the perfecting of the constant speed propeller; tremendous developments in instrumentation; the use of deicing equipment; and the current efforts to reduce or eliminate pilot fatigue by making the pilot's job easier and his working conditions more comfortable. The important advances in the field of meteorology, radio communication and airway traffic control should also be stressed.

AIRPLANE CHARACTERISTICS.

The final curves, Fig. 16, illustrate trends of airplane characteristics. Cruising speed, in ten years, has roughly

FIG. 16.



increased from one hundred to two hundred miles an hour—16(*A*). A rather slight flattening-out tendency is now evident although there will be a substantial lapse of time before the limit for certain classes of equipment is reached. In the graph of 16(*B*) are plotted the trends of wing and power loadings. Noteworthy is the flattening-out of the wing loading trend

curve for landplanes at a figure of just under thirty-five pounds per square foot. It is likely that seaplane loading will continue upward although both may be further increased (than shown by these curves) as the result of introduction of assisted take-off means. Power loadings have not decreased greatly and will probably stabilize at about their present figure.

In connection with landing speeds, Fig. 16(*C*), the flattening-out tendency of the curve is indicated, but it should be mentioned that in general it can be shown that for equal safety, landing speeds can legitimately increase proportionately to the sixth root of the gross weight. Here again therefore, the curve depicts the trend for the largest sizes of equipment and it may be expected that for smaller planes, the landing speed will be less.

Next we consider cruising altitude, graph (*D*) of Fig. 16, where the jumps represent for the most part changes in the powerplant which permitted economical flight at successively higher altitudes. Starting from just over sea level, there was a jump in the DC-2 airplane to cruising at approximately ten thousand feet which remained the case until the present time. Equipment just about to make its appearance will raise this to twenty thousand feet and it is my belief that eventually thirty-five thousand feet will be utilized for certain classes of equipment and service.

MODERN AIR TRANSPORT PLANES.

These curves then, show the trend. Let us now see some of the most modern air transport planes operating at the present time or about to be placed in service. To start off again at the point where we previously stopped, the Douglas DC-3 airplane, let us note in Fig. 17 the interior of this ship as used by United Airlines between New York and Chicago. The picture speaks for itself as to the provisions which are made for passenger comfort. Figure 18 shows the interior of a DC-3 accommodating twenty-one passengers as used on most of the airlines in this country and many abroad.

In Fig. 19 is a view of the Short Empire Flying Boat which is a thoroughly modern piece of equipment used by

FIG. 17.

Douglas DC-3, interior, 1937.

FIG. 18.

Douglas DC-3, interior, 1937.

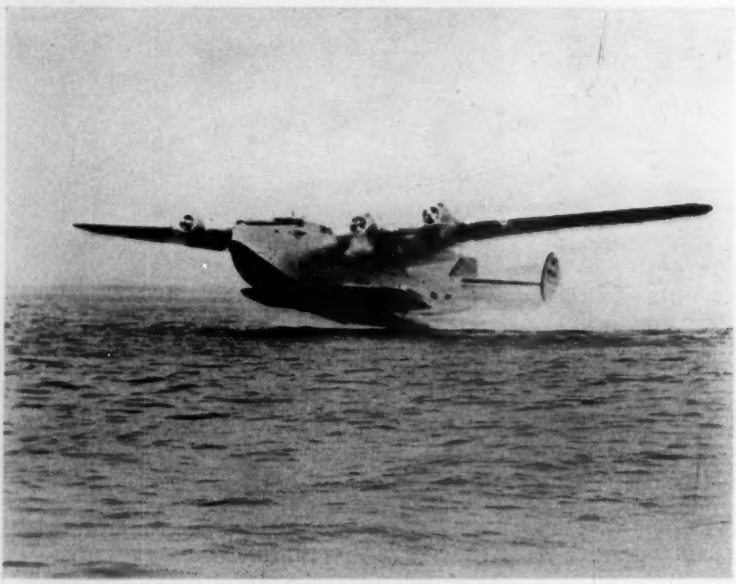
Imperial Airways and seen in this country on its trial trans-Atlantic flights and in the New York-to-Bermuda service last year.

Next we see in Fig. 20 the Boeing 314 which has done such yeoman service in Pan American trans-Atlantic operations.

FIG. 19.

Short Empire flying boat, 1937.

FIG. 20.

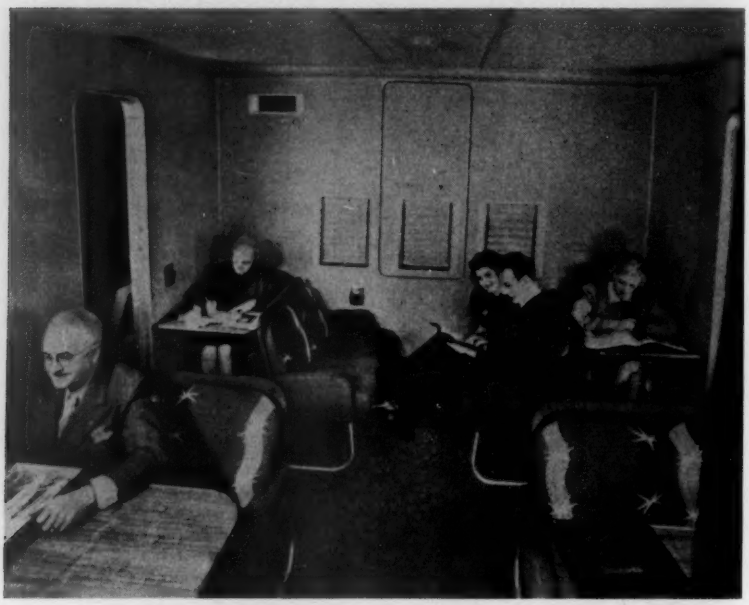


Boeing 314 Clipper, 1938.

Another view, of the interior, of this ship in Fig. 21 gives an idea of the spaciousness and comfort that the passengers enjoy when travelling on these Clippers.

The Lockheed 14 in Fig. 22, although smaller in size than the DC-3, provides a very excellent and comfortable service at the high cruising speed of two hundred and twenty miles an hour.

FIG. 21.



Boeing 314 Clipper, interior.

Figure 23 shows the DC-5, about to be put into feeder line service in this country. It is noteworthy for the introduction of the tricycle landing gear.

In Fig. 24, there is shown a very fine view of the Boeing 307 Stratoliner, several of which were recently ordered by TWA and Pan American, to be placed in service this year. And, in Fig. 25 we have a DC-4, the largest of land air transports yet produced. It is noteworthy, not only for its fine performance and load carrying ability but again for the introduction of the tricycle landing gear.

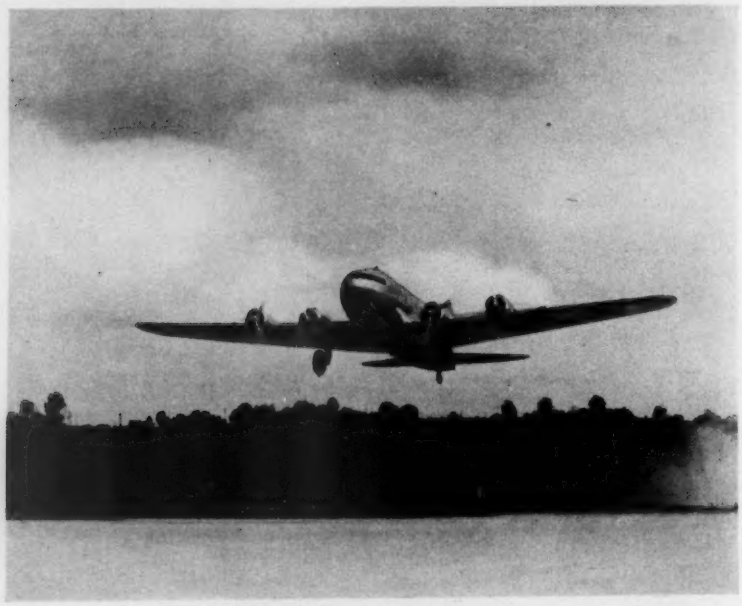
FIG. 22.

Lockheed 14, 1937.

FIG. 23.

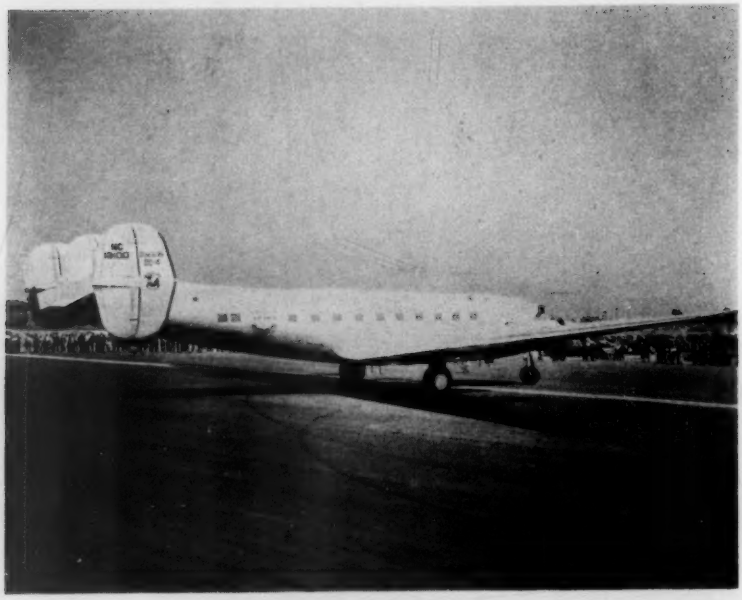
Douglas DC-5, 1939.

FIG. 24.



Boeing 307 stratoliner, 1939.

FIG. 25.



Douglas DC-4, 1939.

THE FUTURE FOR PERFORMANCE.

And now to examine three more tables indicating the possibilities of the future for speed and range. In Fig. 26 are shown the factors which made possible the eighty per cent. increase in cruising speeds which occurred from 1929 to 1939. The preponderant effect of aerodynamic cleanness shown in

FIG. 26.

Airplane Cruising Speeds.

Factors Causing Increases of the Past Ten Years and Possibilities of the Next Ten Years.

Item.	Description of the Item in Detail and Improvements Involved.	Speed Improvement.	
		Actual.	Possibilities.
		1929–1939.	1939–1949.
"Wasted" Drag	Streamline shape; smooth surfaces; interferences; improved nacelles; elimination unnecessarily exposed parts; improved Reynolds Number accompanying size increase.	% 36	% 9
Wing Loading	Improved flaps and sections.	17	4
Power Loading	Increased allowable landing speed with size increase; higher takeoff powers with improved fuels.	8	0
Altitude Flying	Progressively from sea level to 10,000 feet, to 35,000 feet.	9	18
Wing Efficiency	By more perfect taper; thinner and improved sections; etc.	7	2
Induced Drag	By higher aspect ratios; elliptical wings; etc.	1	2
Propeller	Operation at better V/ND; blade section improvement.	1	2
Structural	Weight reductions due larger size, better materials, and improved design.	1	3
		80	40
Resultant Cruising Speeds	Average values typical of the period.	105 to 190 MPH	190 to 266 MPH

Notes: Further, but more remote possibilities are: Cooling drag reductions or elimination; very high wing loadings using Assisted Takeoff; greater than normal powerplant improvements; complete laminar flow by section change combined with small chord or boundary layer control.

the first item is noteworthy, with the additional substantial items of increased wing loading, decreased power loading, flying at higher altitudes, and wing efficiency; following with minor improvements in the last three items, induced drag, propeller efficiency, and weight reductions brought about by structural weight improvement. These features have brought the speed from one hundred and five to one hundred and

ninety miles an hour. My prognostication of increases to two hundred and sixty-six miles an hour cruising speeds in the next ten years will be effected by the same items but with a different relative proportion for each as shown in the second column of Fig. 26. The importance played by flying at still higher altitudes should be noted together with important improvements in drag reduction, although of only one-quarter the magnitude that maintained for the last ten years. The reason for this is shown in Fig. 27 where it will be observed that

FIG. 27.

Ten Years Advance in Aerodynamic Cleanness.

Year.	Item.	
	* Wasted Horsepower.	Actual Speed in % of † Streamline Speed.
1929	66	65
1939	20	90

horsepower "wasted" in overcoming unnecessary drag is now but twenty per cent. of the total as against sixty-six per cent. ten years ago. At that time, speeds made good were only sixty-five per cent. of what they would have been if all this unnecessary drag were eliminated and a perfect streamline airplane produced. This proportion of actual speed to streamline speed is now ninety per cent., leaving only a short way to go in possible improvement.

Figure 28 indicates three factors which will contribute towards increasing range by about thirty per cent. in the next ten years. It is believed these are self-explanatory. How-

FIG. 28.

Airplane Range.

Factors Causing Increases of the Next Ten Years:

Speed increases automatically improve Range—The improvement may be of the order of	15%
Reduction in *Specific Fuel Consumption*	10%
Structural Weight Reductions	5%
Total	30%

* "Wasted Horsepower" is horsepower consumed in overcoming the drag of unnecessarily exposed parts or of non-streamline shapes.

† "Streamline Speed" is the speed the airplane would make at a given altitude if its only drag were smooth flat plate skin friction; drag caused by efficient cooling of the engine; and induced drag due to lift.

Figures are obtained by using the method of B. Melvill Jones.

ever, it should be noted that all of the speed increase shown on Fig. 26 will not go into range increase since that proportion which will be attained by flying at high altitudes will not result in range improvement and, as well, the weight reductions resulting from structural improvements cannot all be used both for speed and range increase. Then too, cruising velocities are higher than schedule speeds which are reduced by time losses in take-off and landing to give what are known as block-to-block speeds. As these losses are constant regardless of cruising speed, the final range increase due to cruising speed improvement is about fifteen per cent. as shown. A further ten per cent. reduction in specific fuel consumption is expected although it will be difficult to obtain when it is realized that in the past ten years, specific fuel consumption has dropped from about .52 pounds per horsepower hour to about .41, a twenty-one per cent. improvement.

THE FUTURE OF AIR TRANSPORTATION.

Now I shall briefly discuss the future of air transportation. Let us look at Fig. 29 which shows the New North Beach,

FIG. 29.

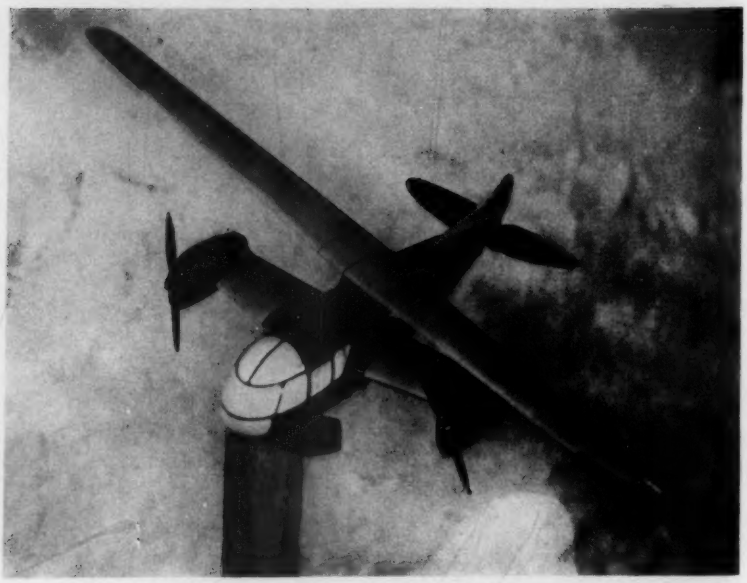
New York La Guardia airport—1939.

La Guardia Airport in New York City from which operations started on December 1, 1939. This magnificent airdrome with its long all-direction runways and fine hangars and wait-

FIG. 30.

Mayo composite airplane, 1939.

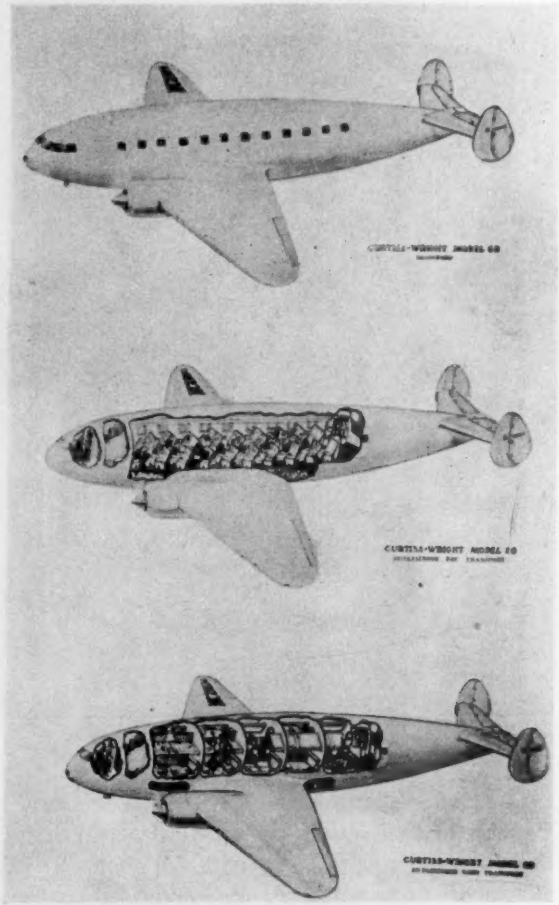
FIG. 31.



Transport helicopter proposal.

ing rooms, is a definite indication of air transportation's future expansion. Just as those cities which provided themselves with facilities and inducements for the railroads to pass

FIG. 32.



Curtiss-Wright Model Twenty—1940.

within their limits in the 1870's and '80's, made certain their future as centers of commerce and industry, so likewise the case will be now for those cities that provide themselves with

proper airport facilities. At North Beach dual facilities for land and water operations are provided.

Next are shown views of flying equipment which may be important in further development. First, in Fig. 30, there is the Mayo Composite Airplane arrangement which by means of assisted take-off provides the operating, or top unit, with increased speed and range which may therefore be a factor in trans-Atlantic mail flying.

FIG. 33.

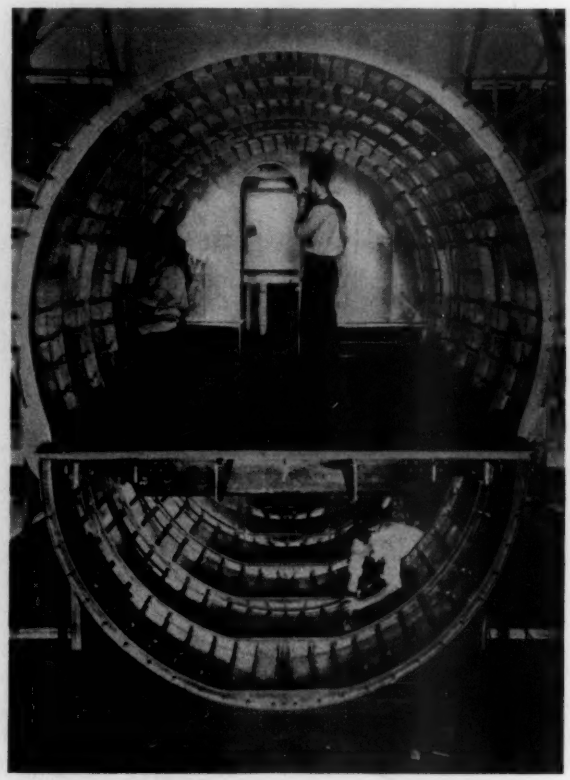
Curtiss-Wright Model Twenty, interior.

In Fig. 31 there is shown a view of a model of a helicopter, a type of aircraft which will be used for transporting mail and passengers from airports to roof-tops in the centers of cities and even, in many cases, for short haul traffic directly between city centers. In addition it may revolutionize our conception of private owner Aircraft.

Figure 32 is a view of the Curtiss-Wright Model Twenty with pressurized cabin and with extremely large baggage and express compartments. A noteworthy contribution to

economy of operation is expected when this plane goes into service, making it eminently suitable for use between large centers of population. Other views of this plane during its development are shown in Fig. 33, which is an interior view

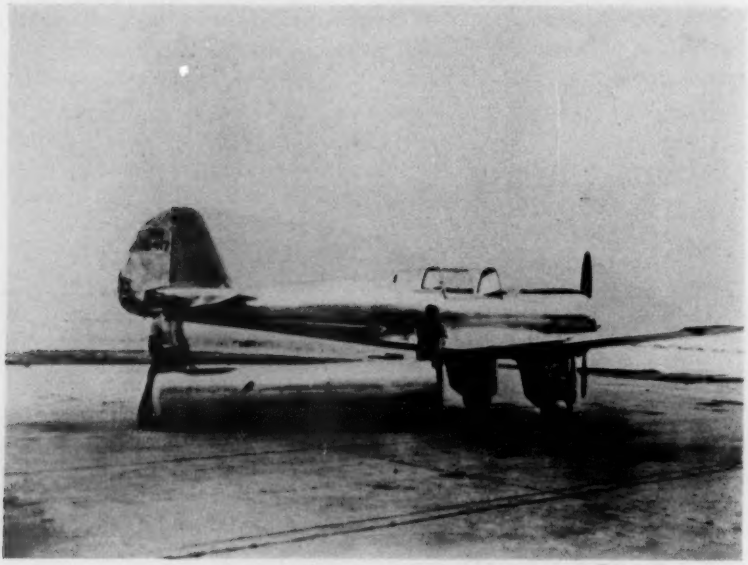
FIG. 34.



Curtiss-Wright Model Twenty. Provision for pressurization and cargo space.

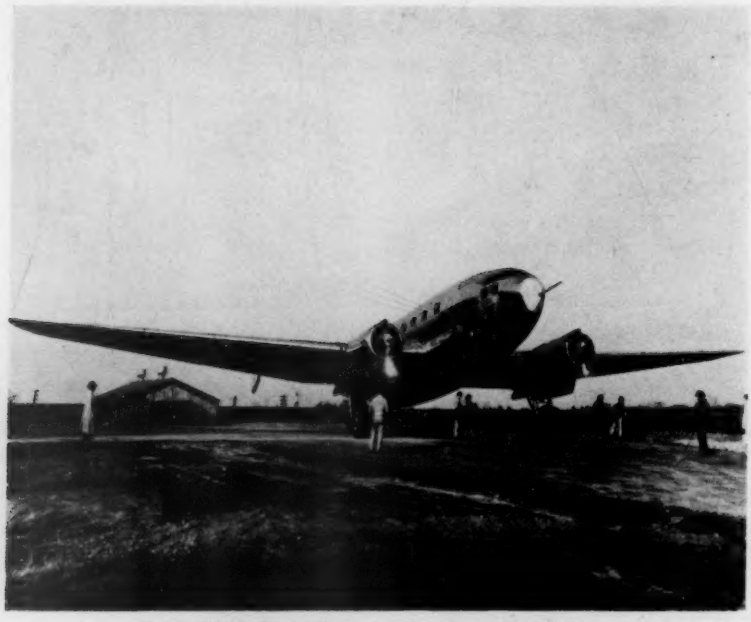
of one arrangement which accommodates thirty passengers, and Fig. 34 which illustrates, in a construction view, the unique manner in which structural provision for pressurization is provided accompanied by provision for tremendous bulk of baggage, express and freight under the cabin floor. An idea of the size of the plane is shown in Fig. 35 where one

FIG. 35.



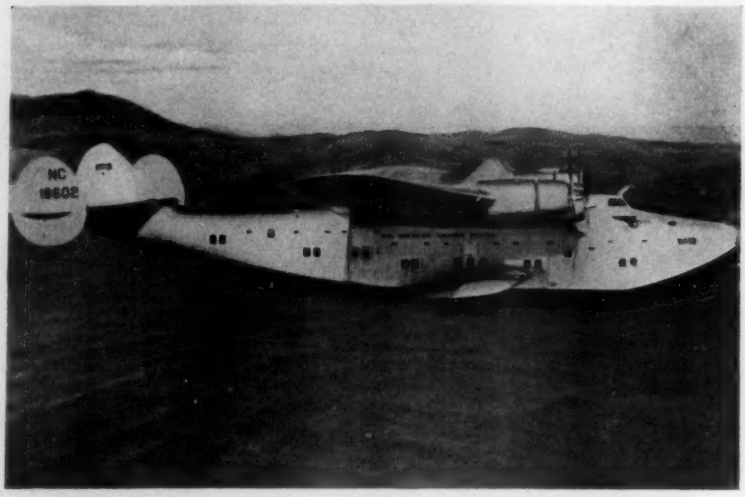
Curtiss-Wright Model Twenty—Fuel tank—Size comparison.

FIG. 36.



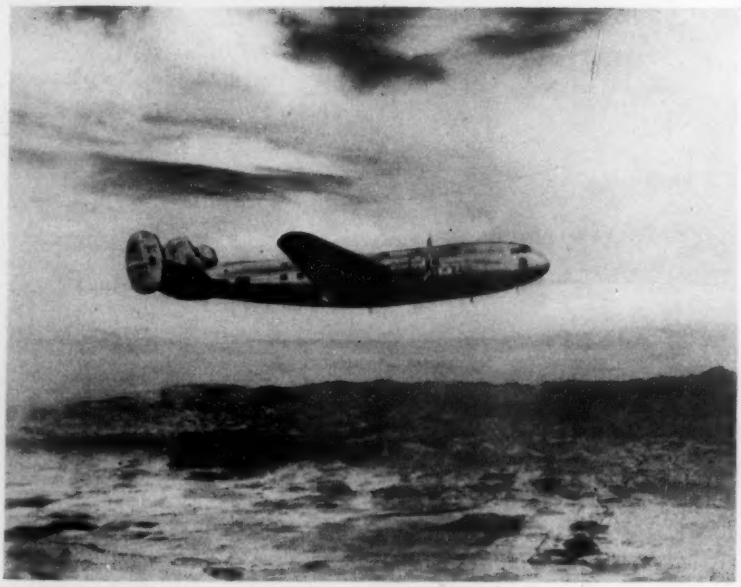
Curtiss-Wright Model Twenty. Warming up for flight test.

FIG. 37.



Boeing 314, Clipper.

FIG. 38.



Douglas DC-4.

of its four gas tanks is set beside a two-place training plane; the tank is almost as large as the entire fuselage of the training craft. Figure 36 is a view of the plane outside the factory while being prepared for its initial flights. This plane will

FIG. 39.

Sikorsky proposed ocean airliner, interior.

FIG. 40.

Sikorsky proposed ocean liner.

provide still higher standards of safety and economy in operations.

The final illustrations of this paper are views of the most modern equipment now flying; the beautiful Boeing Pan American Clipper (Fig. 37) and the Douglas DC-4 (Fig. 38). Last of all, two views illustrating a prediction of Mr. Sikorsky of the trans-Atlantic airliner of the future, Fig. 39 showing the dining salon and Fig. 40, the flying boat itself in the air.

CONCLUSION.

We have thus reviewed transport aviation, showing its history from "infancy" to 1911 through "romantic childhood" to 1926; "painful adolescence" to 1931; its satisfactorily progressing "young manhood" to the present time; and its promise of "maturity" for the future. One cannot but be inspired by contemplating some of the following:

A recent TWA Timetable Schedule headed "Europe—New York—Chicago—Los Angeles—San Francisco—Asia";

The growth of one of the U. S. air systems, American Airlines, Inc., from its first passenger in April, 1927, to its millionth in February, 1937, and its two millionth in September, 1939;

The fact that our domestic airlines are now flying over two hundred and fifty thousand plane miles each day; the equivalent of eighty round trips from New York to Los Angeles or of ten trips around the world at the Equator, or perhaps better still, one to the Moon;

The fact that there are thirty large airliners flying daily each way on scheduled trips between New York and Chicago (a greater number than holds for through train schedules);

And the fact that we are now enjoying regular service coast-to-coast in just under seventeen hours which we may confidently expect will, within a reasonable time, be reduced to twelve; and regular trans-Atlantic trips of twenty-four hours duration at present which will be cut eventually to eighteen.

These factors are all indicative of the inspiring future of air transportation.

I cannot close without again referring to my belief that this bringing of peoples closer together will be a tremendously important factor in maintaining the peace of the world once the present war is over. This vision was, strangely enough, first pronounced almost a hundred years ago by William S. Henson, the inventor of an "aerial steam carriage" in 1843. His vision of the airplane as represented mechanically in his invention was remarkable in its close approximation in many respects to our present day airplanes, but what he wrote concerning his vision of human relations as affected by his invention is even more important and is quoted below:

> ". . . The changes which must follow the first aerial voyage of one hundred miles in length must be great, may be astounding to our present notions, may be dashed as all human advances are with subtractive evils, but they must be largely beneficial to the human family. It is no considerable earnest of future good that the very nature of the design compels us to consider all mankind as one community. . . . when men are strangers, they are ready to become enemies; render them mutually acquainted, and they soon become mutually useful, and when their interests are at stake we may safely reckon on their continued and abiding friendship . . . ."

Let us continue to improve our air transport planes and our air transport services. Let us see that the objectives finally accomplished are those envisioned above. And make certain that it shall not come to pass that the air conquers man, but that truly man conquers the air!

THE ACCELERATED FLOW METHOD FOR RAPID REACTIONS.*

BY

BRITTON CHANCE.

PART I. ANALYSIS.

I. INTRODUCTION.

The purpose of this research is to extend the range of the continuous flow method of Hartridge and Roughton.[1] It is desired to study the kinetics of enzyme reactions where the extinction coefficients of the materials are often small and the concentration and quantity available are limited by preparation methods. It is also desired to measure very rapid chemical processes where the absolute rate of a bimolecular process could be reduced by dilution of the reactants.

Improvements have been made in the attainable flow velocity, the sensitivity and speed of response of the photoelectric system, and the fluid economy. An automatic method for measuring flow velocity, and for simultaneously recording flow velocity and light absorption, has also been developed.

The principle of the method is illustrated in Fig. 1, and is essentially the same as the original method of Hartridge and Roughton [1] and Roughton and Millikan.[2] Reactants A and B, one colored, are placed in their respective syringes A and B. The syringes are rapidly discharged and the materials flow through tangential jets 1 and 2 where they are rapidly mixed. The mixed reactants flow down the tube to s_1 and s_2, the place of observation. From s_1 to s_2 a light beam of suitable wavelength shines through the reactants and falls upon a photocell P. In this way the amount of the colored reactant that has disappeared in the interval that it has taken the fluid to move from the mixing chamber to the observation place is measured.

* Contribution from the Department of Chemistry and Chemical Engineering of the University of Pennsylvania and the Physiological Laboratory, Cambridge, England.

The flow velocity is u_0 from which the time interval is

$$t = \frac{s_1 + s_2}{2u_0}. \qquad (1)$$

In the present method the flow velocity has been increased by using small bore 1 cc. tuberculin syringes which could be manually discharged at a high velocity. Cavitation of the flow, found to be a limitation on high flow velocity, has been studied and greatly decreased.

FIG. 1.

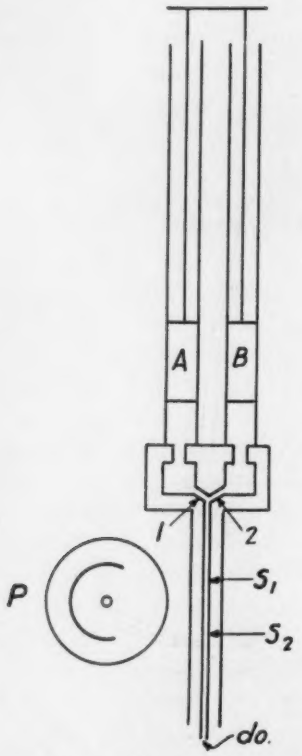


Diagram of the principle of the flow method.

Continuous recording of kinetic curves was obtained simply by employing a device to give a continuous indication of flow velocity and the flow velocity is varied throughout a

desired range by the manual syringe drive. Since flow velocity is varied, the time interval is also varied. The flow velocity indication is therefore recorded graphically against simultaneous values of the extent of reaction as determined by the photoelectric system.

Improvement in fluid economy has been due to the development of the accelerated flow method which required an increase in the speed of response of the photoelectric amplifier and the use of cathode ray tube photography for continuous recording. The continuous recording method also increased the amount of information obtained from a given quantity of material.

Accurate data for relatively long times can now be obtained by the stopped flow method which rapidly stops the flow in the observation tube and continuously records changes in absorption of a reactant as a function of time.

The speed of response of the photoelectric system has been greatly increased by the use of inverse feedback in the amplifier.

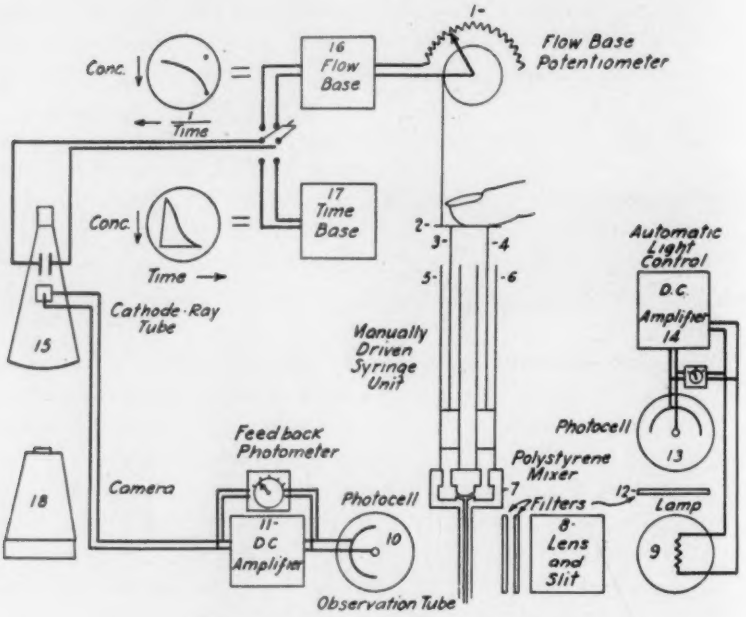
The development of automatic light intensity control has increased the useful sensitivity of the photoelectric system.

The manual syringe drive has enabled the construction of a small compact apparatus of high mechanical rigidity.

The final apparatus is shown in Fig. 2. 1 is a potentiometer used for obtaining a continuous indication of flow velocity and is attached to syringe plungers 3 and 4 by a chain. The syringe plungers are manually driven by pushing plate 2. The tuberculin type syringes, 5 and 6, are screwed into polystyrene mixer 7. The glass observation tube is sealed into mixer 7. Lens 8, transmitting light from exciter lamp 9 sends a narrow beam of light through the observation tube onto absorption measurement photocell 10. This photocell is directly connected to the amplifier 11. Lamp 9 also shines through an infra-red filter 12 onto automatic light control photocell 13, directly connected to amplifier 14. Amplifier 11 operates the vertical axis of the cathode ray tube 15 while the horizontal axis is operated by either the flow base 16 or the time base 17. The record of the kinetic curve is obtained by camera 18.

The accelerated flow method is used for recording the kinetics of very rapid reactions and the data is obtained in the form of a curve of concentration against the reciprocal of time as obtained from the flow base. The stopped flow method is used for less rapid reactions and a curve of concentration against time is obtained directly by using the time base.

FIG. 2.



The accelerated and the stopped flow methods.

The design of this apparatus has required some knowledge of the fundamental variables of the flow method and their limitations. A study of these factors will now be taken up.

II. THE THEORETICAL LIMITATIONS OF THE FLOW METHOD.

The relative importance of the limiting factors of the flow method must be known before research on any one is justifiable. Millikan[2] has given a table showing the qualitative effects of a number of variables affecting the flow method. Here quantitative relationships and figures of merit for a flow

method, designed to operate under various conditions will be developed. Research upon the important fundamental variables will then be described. Fig. 1 indicates a typical flow apparatus.

1. Time Limited.

The apparatus is to be used in an experiment where there are available large quantities of material in high concentration having intense absorption bands to suit light source and photocell combinations, but whose time of reaction is limited by factors beyond control. The time, t, attainable by the flow method is

$$t = \frac{s_1 + s_2}{2u_0} = \left[\frac{s_1 + s_2}{2}\right]\frac{\pi d_0^2}{4V_1}. \qquad (1)$$

A figure of merit, M, for an apparatus designed to measure rapid reactions under time limited conditions is arbitrarily defined as the reciprocal of the time which the system is capable of measuring.

$$M = \frac{2}{s_1 + s_2}\frac{4V_1}{\pi d_0^2}, \qquad (2)$$

$\frac{s_1 + s_2}{2}$, the distance from the point of mixing to the mean observation point, is limited by the efficiency of mixing.

V_1, the volume of reactants discharged per unit time is limited by the pressure drop which it causes. The allowable pressure drop is limited by strength of materials and power available to discharge the reactants. V_1 is also limited by cavitation of the flow in the observation tube which obscures photoelectric observation.

d_0, the bore of the observation tube, is the most important variable in this case as it appears as a square term and can be made as small as desired in this case if the length of the observation tube is decreased simultaneously with d_0 as will be shown later.

2. (a) Time and Substance Limited.

The apparatus is to be used in an experiment where large quantities of material whose time, extinction coefficient, and/or concentration are limited by factors beyond control.

As before, formula (1) represents the time attainable with the flow method.

The extinction coefficient and the concentration are limited and the factors influencing the sensitivity of the photoelectric system must be considered. For substances obeying Beer's law, the expression for light absorption in a thickness d_0 is

$$\frac{\Delta I'}{I'} = 10^{-\epsilon c d_0}, \tag{3}$$

where ϵ is the molecular extinction coefficient, c the concentration of the reactant whose light absorption changes, $\Delta I'$ the change of original light intensity I' due to a change of c.

As the available material has small values of ϵ and/or c,

$$\Delta I' = I' \epsilon c d_0 \tag{4}$$

if $\frac{\Delta I'}{I'}$ is less than 4 per cent.

I' will depend upon I_0, the intrinsic brightness of the light source per unit area in the region where ϵ is large, and upon the area of the slit of light that passes through the observation tube.

$$I' = I_0(s_2 - s_1) \text{ (slit width)}, \tag{5}$$

where $s_2 - s_1$ is the length of the slit in the direction of the flow. The slit width can be taken as an arbitrary value W, equal to or less than the bore of the observation tube, or the slit width can be made always equal to the bore of the observation tube. In the latter case there is some deviation from Beer's law for large values of light absorption in a circular tube.

$$I' = I_0 W(s_2 - s_1) \tag{6}$$

or

$$I' = I_0 d_0(s_2 - s_1). \tag{7}$$

The voltage, e_{signal}, from a photoemissive cell, receiving a light intensity $\Delta I'$ is

$$e_{signal} = RS\Delta I', \tag{8}$$

where R is the load resistance of the photocell and S is the sensitivity of the photocell in the region where ϵ is large.

Johnson and Llewellyn [3] have shown that the limit to the amplification of the voltage, e_{signal}, is set by thermal agitation voltage, e_{noise}, in the resistance R when e_{signal} is less than 1/20 volt.

$$e_{noise} = \sqrt{1.64 \times 10^{-20} RF}, \tag{9}$$

where F is the band pass of the amplifier. F is related to the speed of response of the amplifier.

It is desirable that the ratio of signal voltage to the noise voltage be large, hence,

$$\frac{e_{signal}}{e_{noise}} = 7.8 \times 10^{9} S \Delta I' \sqrt{\frac{R}{F}} \tag{10}$$

on substitution for $\Delta I'$ from (4) and (6)

$$\frac{e_{signal}}{e_{noise}} = 7.8 \times 10^{9} S \epsilon c W d_0 (s_2 - s_1) I_0 \sqrt{\frac{R}{F}}, \tag{11}$$

on substitution for $\Delta I'$ from (4) and (7)

$$\frac{e_{signal}}{e_{noise}} = 7.8 \times 10^{9} S \epsilon c d_0^2 (s_2 - s_1) I_0 \sqrt{\frac{R}{F}}. \tag{12}$$

A figure of merit, M, for an apparatus designed to measure rapid reactions under substance and time limited conditions is arbitrarily defined as the quotient of the signal to noise ratio of the photoelectric system and the time attainable by the flow system.

Combining (2) and (11)

$$M = 1.0 \times 10^{10} S \epsilon c (s_2 - s_1) \frac{2}{s_1 + s_2} \frac{W V_1 I_0}{d_0} \sqrt{\frac{R}{F}}. \tag{13}$$

Combining (2) and (12)

$$M = 1.0 \times 10^{10} S \epsilon c (s_2 - s_1) \frac{2}{s_1 + s_2} V_1 I_0 \sqrt{\frac{R}{F}}. \tag{14}$$

V_1 and $\frac{s_1 + s_2}{2}$ are limited by factors described in case 1.

ϵ and c are limited by factors beyond control.

S, the photocell sensitivity, is limited by available photocells and their spectral characteristics.

$s_2 - s_1$ is the slit length of the light beam in the direction of flow and is limited by the error it causes in measurements of monomolecular and higher order reactions.

I_0, the intrinsic light source intensity per unit area in the region where ϵ is large, is limited by available lamps and their spectral characteristics. I_0 is also limited by the error caused by fluctuations in supply voltage to the lamp and by the nature of the relation between I_0 and supply voltage for a particular lamp.

R is the photocell load resistance and is limited by leakage and grid currents in the first amplifier tube.

F is the band pass of the amplifier and may be made as small as possible as the supply of material is not limited in this case.

d_0, the bore of the observation tube, is not a factor in this case since a decrease in d_0 would require a corresponding increase in the concentration of reactants.

W, the slit width, should be increased until it is equal to d_0.

It is well to note here the case where e_{signal} is greater than 1/20 volt. Johnson [3] has shown that the limit to amplification is set by the shot noise of the photocell cathode.

$$e_{noise} = \sqrt{31.8 \times 10^{-20} i R^2 F}, \qquad (12a)$$

where i is the total photocurrent and

$$i = SI'. \qquad (12b)$$

From (4), (6), (8) and (12a)

$$\frac{e_{signal}}{e_{noise}} = 1.74 \times 10^9 \epsilon c d_0 \sqrt{\frac{I_0(s_2 - s_1)WS}{F}}, \qquad (12c)$$

and from (1) and (12c)

$$M = 2.2 \times 10^9 \frac{\epsilon c}{d_0} V_1 \frac{2}{s_1 + s_2} \sqrt{\frac{I_0(s_2 - s_1)WS}{F}}, \qquad (12d)$$

and for $W = d_0$

$$M = 2.2 \times 10^9 \epsilon c V_1 \frac{2}{s_1 + s_2} \sqrt{\frac{I_0(s_2 - s_1)S}{d_0 F}}. \qquad (12e)$$

It is notable that this case is more like the time limited case in that a small value of $\frac{s_1 + s_2}{2}$ and d_0 are desirable and

the slit length is of secondary importance. R does not appear and I_0 is of secondary importance.

2. (b) Time and Substance Limited Visual Spectroscopy.

The apparatus is to be used for a visual study of spectral changes taking place in the observation tube as originally done by Hartridge and Roughton.[1] The trough thickness is the important variable in this case. If observations are made perpendicular to the direction of flow in a circular tube, the trough thickness is d_0. The figure of merit is assumed to be the quotient of the trough thickness and the time measurable by the system. From (1)

$$M = \frac{2}{s_1 + s_2} \times \frac{4V_1}{\pi d_0} . \qquad (14a)$$

For observation in a rectangular tube

$$M = \frac{2V_1}{W^2} \text{ where } W = \text{tube width.} \qquad (14b)$$

If, however, the spectroscopic observation is made parallel to the direction of flow, the trough thickness is $s_2 - s_1$.

Hence from (1)

$$M = 2\frac{(s_2 - s_1)}{s_1 + s_2} \times \frac{4V_1}{\pi d_0^2} . \qquad (14c)$$

For observation in a square tube

$$M = \frac{2V_1}{W^2} \text{ where } W = \text{tube width.} \qquad (14d)$$

A comparison of the two cases indicates that the latter is superior to the former by a factor d_0 used in the first case. This is due to the fact that a circular observation tube is used. When rectangular observation tubes are used, the two methods are of equal merit. It is worthy of note that such a large difference of merit might make it profitable to use either observation parallel to the direction of flow or rectangular observation tubes for photoelectric observation in substance limited cases. However, it would be necessary to re-establish criteria for character of flow and mixing in such tubes.

2. (c) Time and Substance Limited Luminescent Reactions.

The apparatus is to be used in an experiment where large quantities of material whose time and intensity of luminescence are limited by factors beyond control.

The amount of light from a luminescent reaction is assumed to be proportional to the volume of the observation tube seen by the photocell.

$$\Delta I' = L(s_2 - s_1)\frac{\pi d_0^2}{4}, \tag{15}$$

where L is the light intensity per unit volume of luminescent material, $s_2 - s_1$, the length of the observation tube seen by the photocell, and d_0 the bore of the observation tube.

From (8) and (9)

$$\frac{e_{\text{signal}}}{e_{\text{noise}}} = 7.8 \times 10^9 SL(s_2 - s_1)\frac{\pi d_0^2}{4}\sqrt{\frac{R}{F}} \tag{16}$$

and from (1) and (16)

$$M = 1.0 \times 10^{10} SL(s_2 - s_1)\frac{2}{s_1 + s_2} V_1 \sqrt{\frac{R}{F}}. \tag{17}$$

These expressions are identical to those of case 2(*a*) except that L replaces $\epsilon c I_0$.

3. Time, Substance and Quantity Limited.
(a) Continuous Flow Method.

The apparatus is to be used in an experiment where the time, extinction coefficient and/or concentration, and quantity of the material are limited by factors beyond control.

For a continuous flow method, the quantity of fluid required for an observation is equal to the product of the flow rate in volume per unit time times the length of time that the fluid is kept in motion. The assumption is made that the flow is started and stopped in a time short compared to the period of flow at uniform velocity. The volume of fluid, V, required for a single measurement, is

$$V = V_1 t^1 \tag{18}$$

where V_1 is the volume per unit time discharged at uniform velocity and t^1 is the duration of the discharge.

t^1 must be sufficiently long to permit the photoelectric system to make a measurement of a change in absorption. Guillemin [4] has shown that the speed of response of a linear passive system to a suddenly applied voltage is $\frac{1}{2F}$ where F is the pass band of this system and F includes zero frequency. Experimental tests of this formula for feedback amplifiers have not been made. The amplifier used here has been tested not only for F but also for speed of response and in this particular case the response speed is not less than that indicated by $\frac{1}{2F}$. The value of F used experimentally should be considerably larger than that required by this formula until such tests are made. With this limitation in mind it will be assumed that the speed of response of the photoelectric system is proportional to F and that

$$t^1 = \frac{1}{2F}, \tag{19}$$

$$V = \frac{V_1}{2F}. \tag{20}$$

A figure of merit for a Hartridge-Roughton [1] continuous flow apparatus with infinitely short starting and stopping periods used under these conditions is arbitrarily taken to be the signal to noise ratio of the photocell system divided by the product of the time measurable by the system and the quantity of fluid required to make a measurement of the extent of reaction with the photocell system.

From (14) and (20)

$$M = 2.0 \times 10^{10} S\epsilon c(s_2 - s_1) \frac{2}{s_1 + s_2} I_0 \sqrt{RF}. \tag{21}$$

F, the band-pass of the amplifier must be made large. F is limited by R and the inherent capacitance of the photocell and first amplifier tube.

V_1 is no longer important as an increase in flow velocity increases the fluid consumed.

b. Accelerated Flow Method.

As F becomes large t^1, the period of continuous flow, may be made so small that it becomes comparable to the time required to start and stop the flow and the assumed conditions of the previous case are violated. The accelerated flow method takes advantage of this and increases F so that measurements of the extent of reaction can be made while the flow rate is varying. In this way a continuous record of the kinetics of the reaction is obtained.

If it is assumed that the flow accelerates linearly, the flow rate at any time t^1 is

$$V_1 = at^1, \tag{22}$$

where a is the rate of change of flow velocity in volume per second per second.

The quantity of fluid, V, used in the interval t_1 is,

$$V = \int_0^{t_1} V_1 dt^1 = \tfrac{1}{2}at^{1^2}. \tag{23}$$

It is assumed that the flow is suddenly stopped when a desired value of V_1 is obtained.

(From (1) and (22)

$$tt^1 = \frac{s_1 + s_2}{2a} \frac{\pi d_0^2}{4}. \tag{24}$$

The time, t, measurable by the system is a function of the actual passage of time and decreases as t^1 increases.

A figure of merit for the accelerated flow method designed to measure rapid reactions under quantity, substance, and time limited conditions is defined as for case 3(a).

From (14), (19), (22) and (23)

$$M = 4 \times 10^{10} S\epsilon c(s_2 - s_1) \frac{2}{s_1 + s_2} I_0\sqrt{RF}, \tag{25}$$

The figure of merit is twice that attainable by the continuous flow case with infinitely short starting and stopping periods. However a complete kinetic curve is obtained here while only one measurement was obtained in the continuous flow case.

Although a and t^1 do not directly appear, (24) shows that a and t^1 must be adjusted so that the desired value of t is

obtained. As a is increased the quantity of reactants required to reach a given time, t, is decreased.

A limitation upon a large value of a is an error introduced into the calculation of time from (2), since the flow velocity is not constant over the interval t.

c. The Stopped Flow Method.

When the flow is suddenly stopped some particle of mixed reactants will come to rest at the observation point and the rate of reaction of the substances in this particle may be determined directly as a function of time. It is again assumed that the flow stops with a linear negative acceleration. This acceleration may be much larger than that permissible to use with the accelerated flow method. If the particle leaves the mixing chamber with a velocity V_1 and arrives at the observation point in a time t, then

$$t = \frac{s_1 + s_2}{2} \frac{\pi d_0^2}{4} \cdot \frac{2}{V_1} . \tag{26}$$

The volume of reactants required is

$$V = \frac{V_1 t}{2} . \tag{27}$$

The volume of reactants used in attaining flow velocity V_1 is not considered as it is useful in obtaining data by the accelerated flow method or could be made very small by using very large values of a for starting and stopping the flow.

A figure of merit for the stopped flow method for measuring rapid reactions under quantity, substance, and time limited conditions is defined as for case 3(a).

From (14) (26) and (27)

$$M = 2.0 \times 10^{10} S\epsilon c(s_2 - s_1) \frac{2}{s_1 + s_2} I_0 \sqrt{RF}. \tag{21}$$

Here the figure of merit is equal to that attainable by the continuous flow case with infinitely short starting and stopping periods. The method is, however, no longer a flow method but is a quick mix-quick stop method using the advantages of the Hartridge-Roughton mixing method. If the time of stopping is made equal to or less than the time to

be measured, F can be made sufficiently large to make the method applicable over a considerable time range and can be used to supplement the accelerated flow method. The stopped flow method, however, does not involve the measurement of V_1 as do the accelerated and continuous flow methods.

The relative importance of the fundamental factors affecting the flow method has been determined. There are three important cases.

1. Time limited—

$$M = \frac{2}{s_1 + s_2} \cdot \frac{4V_1}{\pi d_0^2}. \qquad (2)$$

2. Time and substance limited—

$$M = 1.0 \times 10^{10} S\epsilon c(s_2 - s_1) \frac{2}{s_1 + s_2} V_1 I_0 \sqrt{\frac{R}{F}}. \qquad (14)$$

3. Time, substance, and quantity limited—

$$M = 2.0 \times 10^{10} S\epsilon c(s_2 - s_1) \frac{2}{s_1 + s_2} I_0 \sqrt{RF}. \qquad (21)$$

It is now justifiable to analyze these fundamental variables in order to design an apparatus having a high figure of merit. It will also be possible to assign numerical values representing reasonable limits to some of these factors.

ANALYSIS OF FUNDAMENTAL VARIABLES OF THE FLOW METHOD.

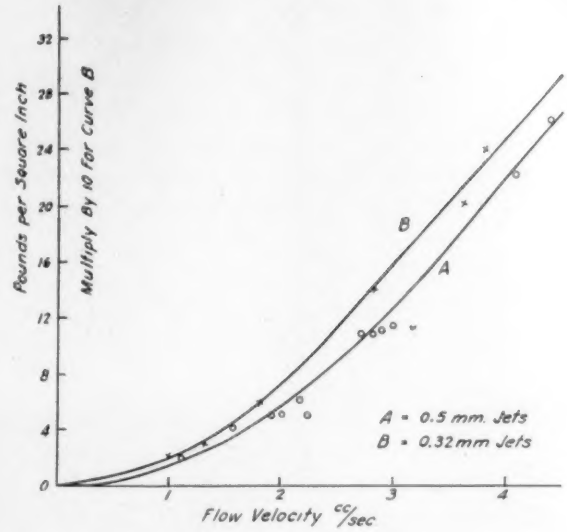
1. The Hydraulics of the Flow Method.

The preceding section has shown that V_1, the volume of reactants discharged from the observation tube per unit time, is of fundamental importance. A limitation on V_1 is the pressure drop across the mixing jets and the observation tube. This pressure drop and the factors influencing it was studied by direct experiment and by the use of the Prandtl-Karman[7] formulæ. It is not felt that it is justifiable to apply the Prandtl-Karman equations to combinations of mixing chambers and observation tubes without experiment.

Experimental.

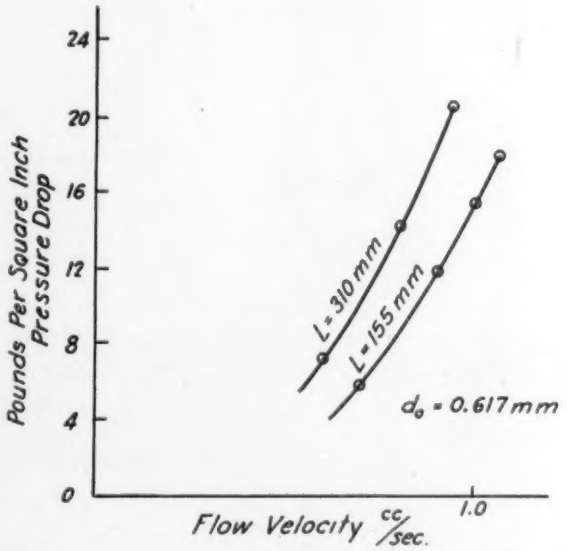
The experimental procedure for obtaining data at high pressures was as follows. An ordinary pressure gauge tester

FIG. 3.



Pressure drops in two types of mixing chambers.

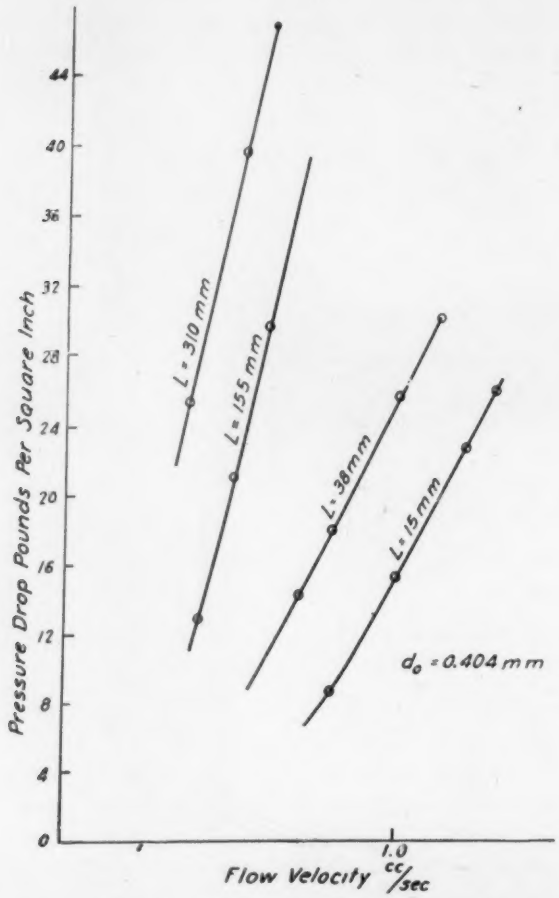
FIG. 4.



Pressure drop in a 0.617 mm. bore observation tube for different lengths.

of 30 cc. capacity was filled with water and the apparatus under test was attached to the nipple usually used for the pressure gauge under test. In this manner pressures as high

FIG. 5.

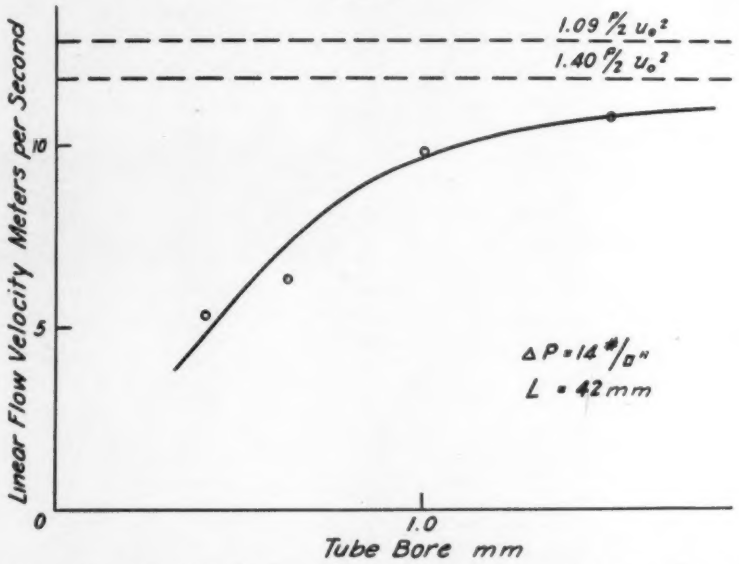


Pressure drop in a 0.404 mm. observation tube for different lengths.

as 220 pounds per square inch and flow rates of 1.3 cc. per second were obtained. The tests were made at constant pressure as measured by a pressure gauge and the flow velocities were determined by a graduate and a stop-watch.

Mixing chambers having very small jet diameter were constructed by spot-welding a No. 26 to a No. 27 (AWG) copper wire and fusing the small metal tee into glass so that there were two entrance jets of No. 26 wire and one outlet to the observation tube of a No. 27 wire. The copper wires were subsequently dissolved out of the glass with aqua regia. A larger mixing chamber was made of glass by fusing in a 1 mm. copper wire and pulling it out just as the glass began

FIG. 6.



Linear flow velocity attainable from observation tubes of different bore for a constant length and pressure. The curve approaches the kinetic energy loss term of the Prandtl-Karman equation for sharp-edged entrances.

to harden. This hole led to the observation tube. Two jets were drilled through the glass into the small hole leading to the observation tube. The data obtained from these two types of mixing chambers is given in Fig. 3. The pressure drop in observation tubes was obtained in the same manner and the data is given in Figs. 4, 5, and 6.

A second method of pressure drop measurement was used for obtaining data at low pressures and high flow velocities for combined mixers and observation tubes. The jets of the mixer were connected to the usual water tap and the pressure

was measured with a mercury manometer and the flows were measured with a stop watch and graduate. Pressures up to one atmosphere and any desired flow velocities were obtained in this way. The mixing chambers and observation tubes tested in this manner were made out of a thermoplastic material in a way described under apparatus construction and were designed according to the findings of the first part of this experiment. The results of these tests are given in Table I. The glass units were constructed by Mr. James

TABLE I.

Pressure Drops in Combined Mixers and Observation Tubes.

Number.	Type of Jets.	Length of Observation Tube mm.	Jet Diameter D_j mm.	Area of Observation Tube A_0 mm^2.	K.	K^1.
1	Two offset tangential	47	1.40	2.27	0.108	0.557 Glass
2	Two opposed	55	1.20	2.27	0.0967	0.499 Glass
3	Four opposed tangential	60	0.50	1.23	0.524	0.787 Glass
CM 1	Four opposed tangential	27	0.60	0.867	0.567	0.425 Polystyrene
CM 2	Four opposed tangential	23	0.60	0.867	0.696	0.522 Polystyrene
FM 2	Two opposed tangential	22	0.60	0.867	0.708	0.532 Polystyrene
FM 3	Two opposed tangential	27	0.60	0.867	0.599	0.448 Polystyrene
FM 4	Two opposed tangential	17	0.396	0.1255	23.0	0.347 Polystyrene
CM 4	Four opposed tangential	35	0.60	0.867	0.441	0.330 Polystyrene

Graham of the University of Pennsylvania Glassblowing Service.

Results of Experiments on Pressure Drops in Mixers and Observation Tubes.

In Fig. 3 the points are experimental values while the curves are parabolas drawn on the assumption that the flow is proportional to the square root of the pressure drop. The agreement is very satisfactory.

In Figs. 4 and 5 the curves are drawn through the experimental points and no simple parabolic relation was found for long tubes. The Reynolds number of some of the points is less than 2,000.

Figure 6 shows the effect of tube bore on attainable flow velocity for a constant tube length. The curve shows that, as far as reducing pressure drop is concerned, the tube bore should be chosen with due regard to the necessary tube length.

Table I shows data obtained from a large number of combined mixing tees and observation tubes. The experiments showed that the parabolic relation held satisfactorily for the dimensions used and the results of an individual experiment are averaged in the value of K. K is derived from

$$K = \frac{\Delta P}{V_1^2}, \tag{28}$$

where ΔP is pounds per square inch pressure drop and V_1 is the flow velocity in cc. per second. (The English system is used for the pressure drop calculations while V_1 is a quantity carried over from the flow method where the metric system is common.)

In order to compare units having observation tubes of different dimensions K^1 is defined by

$$K^1 = KA_0^2, \tag{29}$$

where A_0 is the area of the observation tube in mm.^{2}

From a comparison of values for the units tested, these experiments indicate

1. There is some variation between mixers constructed of identical dimensions and number of jets.
2. The average K of four jet polystyrene mixers is slightly lower than that of the two jet polystyrene mixers.
3. The value of K^1 is not greatly affected by the bore of the observation tube.
4. The pressure drop in jets fits a parabolic curve.
5. The pressure drop in observation tubes fits a parabolic curve for the short tubes tested.

Correlation of the Experimental Results with the Prandtl-Karman[7] Equations.

The Prandtl-Karman [7] formula for pressure drop in turbulent flow in smooth tubes of constant cross-section is

$$\frac{1}{\sqrt{c\Delta p_1}} = 2 \log_{10} (\text{R.N.} \sqrt{c\Delta p_1}) - 0.80. \tag{30}$$

This equation defines $c\Delta p_1$, the pressure drop coefficient. R.N., the Reynold's number is defined

$$\text{R.N.} = \frac{ud}{v}, \tag{31}$$

where u is the linear flow velocity in tube of bore d and v is the kinematic viscosity of the fluid.

The Prandtl-Karman equation for pressure drop Δp, for a tube having a sharp entrance is

$$\Delta p = c\Delta p_1 \frac{L}{d}\frac{\rho}{2}u^2 + 1.40\frac{\rho u^2}{2}, \qquad (32)$$

where L is the length of the tube and ρ is the mass density of the fluid.

It is found that $c\Delta p_1$ usually has a value such that the first term is negligible when $\frac{L}{d} = 40$.

Hence, for "short" tubes and mixing jets;

$$\Delta p = 1.40\frac{\rho}{2}u^2. \qquad (33)$$

A direct comparison of the experimental data and the theory is now possible and is given in Table II. Figure 6

TABLE II.

Pressure Drop Equations.

Apparatus.	Tube Bore (mm.).	Tube Length (mm.).	Experimental Equation.	Calc. Equation.	Form of Calc. Equation.
Small Tee....	0.32 0.36	—	18.1 V_1^2	19.8 V_1^2	$1.09\frac{\rho}{2}u^2$
Medium Tee .	0.65	—	1.39 V_1^2	1.43 V_1^2	$2.24\frac{\rho}{2}u^2$
Straight Tube	0.404	15	15.6 V_1^2	15.4 V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+2.24\frac{\rho}{2}u^2$
Straight Tube	0.404	38	29.4 V_1^2	25.4[2] V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+2.24\frac{\rho}{2}u^2$
Straight Tube	0.404	155	77.0 V_1^2	76.6 V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+2.24\frac{\rho}{2}u^2$
Straight Tube	0.404	310	167 V_1^2	142 V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+2.24\frac{\rho}{2}u^2$
Straight Tube	0.617	155	13 V_1^2	14 V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+8.85\frac{\rho}{2}u^2$
Straight Tube	0.617	310	23 V_1^2	22 V_1^2	$C_{\Delta p_1}\frac{L}{d}\frac{\rho}{2}u^2+8.85\frac{\rho}{2}u^2$

also gives a check on the theory since the flow velocity does approach that indicated by equation (33) as the bore of the tube is increased. The flow velocity is 80 per cent. of that indicated by (33) when $\frac{L}{d} = 40$.

The results show that the experiment and theory agree quite well. The experimental coefficient of the second term is often somewhat larger than the theory indicates. This is probably due to the fact that the jets are placed at right angles to the observation tube and a larger loss of kinetic energy is involved. It has also been shown that the pressure drop due to long observation tubes can be avoided by making the ratio of $\frac{L}{d}$ 40 or less. If this condition is carried out then the relation (28) is justifiable both theoretically and experimentally.

It was stated previously that strength of materials and power available for discharing reactants through the observation tube were limitations on V_1. Figure 6 shows that a pressure of 14 pounds per square inch is required to attain a linear flow of 11 meters per second under the most favorable conditions. Taking $K^1 = 0.4$ as a typical value for a mixing chamber and observation tube, the pressure drop is 36 pounds per square inch for a linear flow of 11 meters per second. Very high pressures will be encountered if it is desired to extend the range of the continuous flow method. Consideration of these facts has lead to the elimination of any possible source of structural weakness or fluid leakage between the driving syringes and the mixing chamber. As the force on the syringe plunger is proportional to the syringe area, for a given flow velocity, small bore syringes have been used to avoid large mechanical forces which would tend to damage the syringes or deflect the photoelectric system.

Cavitation of the flow in the observation tube is another limitation on V_1. It is sufficient here to define cavitation as a turbidity appearing in the flow stream which obscures photoelectric measurement by light transmission. Cavitation appears above a definite value of flow velocity for a particular mixer and observation tube as shown in Table III.

TABLE III.

Flow Velocity for Onset of Cavitation in Glass Mixers and Observation Tubes.

Syringe.	u_0 for Onset of Cavitation (m./sec.).	A_0 mm.	D_j mm.	K^1.
1	6.60	2.27	1.40	0.557
2	8.50	2.27	1.20	0.499
3	7.4	1.23	0.50	0.787

The most significant factor was found here to be the placement of the mixing jets. If the jets were tangential cavitation was observed along the axis of a vortex. If the jets were directly opposed, cavitation occurred at the angles the jets made with the observation tube. A compromise between these extremes enabled the attainment of flow velocities of 25 meters per second without any cavitation.

Evidence is summarized by Hunsaker [8] from much larger tubes showing that cavitation is affected by the shortest radius of the tube entrance or about which the liquid flows, the overall flow velocity, the vapor pressure of the fluid, the amount of entrained air, and the back pressure applied to the system. If the mouth of the observation tube is made bell-shaped, cavitation does not occur.

The only factor tested here has been the back pressure applied to the system. 30 cm. Hg was tried and it was found that the improvement was not worth the additional driving force required.

(To be continued in May issue.)

RESIDUAL CURRENTS IN A.C. DISCHARGES.

BY

J. D. COBINE, Ph.D., and H. KLEMPERER, Dr.Ing.,

Graduate School of Engineering, Harvard University.

ABSTRACT.

A point by point determination is made of the residual current flowing during the reignition period of an a.c. arc between pure graphite electrodes in atmospheric air. The air pressure is varied from 0.14 to 5.4 atmospheres absolute and the gap varied from 1/4 to 5 mm. Alternating current of 60 cycles per second is supplied to the arc by a 10 Kv. power transformer and the r.m.s. discharge current is limited by ohmic resistance to values between 0.05 and 2 amperes. The residual current rises to a peak shortly after the voltage reverses and the current then *decreases* as the recovery voltage increases to its reignition value. The peak of the residual current increases directly with the r.m.s. current of the arc, and is essentially independent of both the length of the gap and the pressure of the gas. The reignition voltage is shown to be a function of the value of residual current existing just prior to ignition. The rate of decay of residual current decreases as gas pressure and gap length are increased.

INTRODUCTION.

In the arc discharge with hot carbon electrodes, the column has a high conductivity after voltage reversal due to the high temperature [1] of the electrodes and the gas. Often no distinctive reignition period exists in such a discharge.[2] For heavy currents the supply of ionized particles is sufficiently great for the current to reverse instantaneously, as in a metallic conductor, i.e. there is no intermediate state visible, and the arc burning-voltage is not exceeded. If the supply of ions in the column is limited, as for relatively small currents, a "saturation" current flows. This current is determined by the thermionic cathode temperature, and precedes the moment when the voltage reaches the ionization value of the gas. An oscillogram of this case is discussed by M. Steenbeck.[3]

[1] A. v. Engel and M. Steenbeck, "Elektrische Gasentladungen," v. 2, pp. 138–150. J. Springer, 1934.

[2] F. C. Todd, T. E. Browne, *Phys. Rev.*, **36**, 732, 1930.

[3] M. Steenbeck, *Zeits. f. Phys.*, **65**, 88, 1930. This oscillogram shows the residual current rising linearly with returning voltage to about 100 ma. at which

Transient currents such as these, occurring between zero voltage and reignition, and due primarily to the after effects of the preceding half-cycle of arcing, may be called "residual currents." The residual current is due to a non-self-supporting discharge and has no characteristic voltage drop.

Under certain conditions, as when well cooled, metallic electrodes or pure graphite electrodes are used, and currents are kept small, the discharge is supported by cold-cathode emission.[4,5] In such "cold cathode arcs" during the reignition period, the high temperature arc column is rapidly cooled because of the proximity of the cold electrodes. Obviously, this effect is more pronounced in short than in long arcs.[6] Under these conditions the reignition voltage has been found to be quite high.[5] This would indicate that the residual current was very much smaller than for the hot-cathode arcs. Research in the region [5] of cold-cathode arcs has shown that unless artificially cooled carbon electrode tips become red-hot for currents exceeding about 1.5 amperes r.m.s., and at such cathode temperatures, reignition takes place at relatively low voltage. On the other hand, with currents of the order of 0.1 amp. and less, the discharge changes into a glow and reignition takes place at very nearly the spark breakdown voltage. Therefore, this investigation of residual currents is concentrated on discharges of from 0.1 to 2 amp. for which the electrodes remain cold and the reignition voltages vary between the spark-breakdown voltage and about twice the arc drop voltage.

The experiments were carried out in air and in nitrogen between spectroscopically pure graphite electrodes. Pure electrodes are necessary because impurities in the material, such as exist in arc-lamp carbons or which may result from touching with the bare hands, tend to decrease the reignition voltage in an irregular and unreproducible way.[7] It is

value saturation is reached. The arc current was 5 amp. r.m.s. and burned between graphite electrodes. Thereafter the current decreases in an exponential manner (a cooling effect) until the voltage reaches the ionization potential when the arc is reestablished.

[4] O. Becken and K. Sommermeyer, *Zeits. f. Phys.*, **102**, 551, 1936.

[5] J. D. Cobine, R. B. Power, L. P. Winsor, *Jour. Appl. Physics*, **10**, 420, 1939.

[6] T. E. Browne, *Trans. A. I. E. E.*, **50**, 1461, 1931.

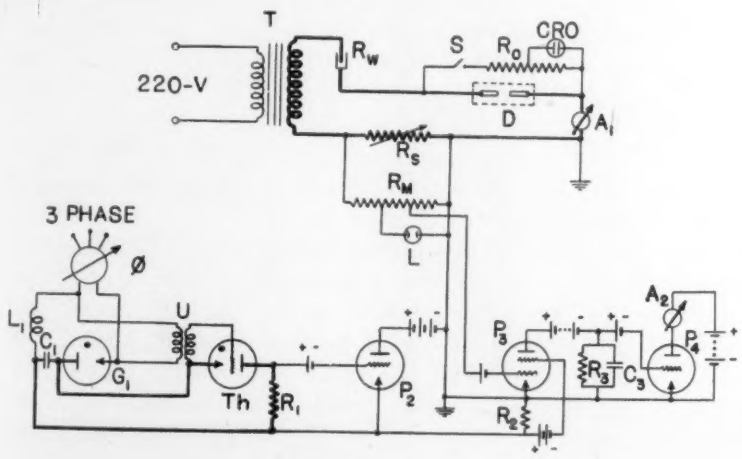
[7] S. S. Mackeown, J. D. Cobine, F. W. Bowden, *Elec. Eng'g.*, **53**, 1081, 1934.

evident that experiments in air, especially with electrodes of combustible material such as graphite, do not exclude the influence of chemical reactions.[8,9]

EXPERIMENTAL.

The experiments were performed in air at pressures ranging from 0.14 to 5.4 atmospheres absolute. The electrodes consisted of pure graphite rods of 6.4 mm. diameter and the separation between the plane end surfaces was varied from $\frac{1}{4}$ mm. to 5 mm. The consistency of gap length was insured by frequent cleaning of the electrode surfaces with a file and resetting the gap. Power was supplied by a 10 kv., 15 kva., 60-cycle transformer. Adjustable water resistors were used to limit the discharge current. The frequency of 60 cycles and the nearly pure ohmic character of the circuit were maintained throughout the experiments. The arc circuit and the measuring circuit are shown in Fig. 1.

FIG. 1.



Experimental Circuit.

A hot-cathode type cathode-ray oscillograph was used in reignition voltage measurements and in determining the waveform of the residual current. With a two-stage amplifier, the

[8] W. G. Duffield, M. D. Waller, *Phil. Mag.*, **40**, 781, 1920.
[9] J. D. Cobine, *Physics*, **7**, 137, 1936.

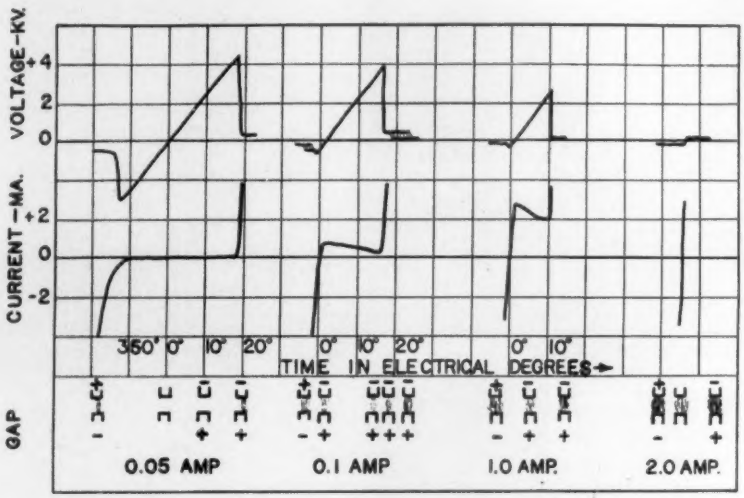
oscillograph showed the presence of residual currents in the region under consideration. However, wave-form determinations by this method were suspected of being unreliable due to distortion in the amplifier. Since the residual current was expected to be about 1000 times smaller than the currents that preceded and followed it, it was obviously out of the question to leave a sensitive measuring instrument connected to the circuit during the entire cycle. A wave-analyzing device [10] using the principle of the Joubert disc was applied to this problem. This method permits a point by point delineation of the unknown wave-shape by making synchronous contacts of short duration, and at various phase angles, between the circuit and the measuring instrument. The measuring circuit, in which all mechanical contacts and motions of the original Joubert method are replaced by electronic means, is shown in Fig. 1. Condenser C_1 is charged by tube G_1 and discharged by thyratron *Th* across resistor R_1 at a moment which is adjustable by means of the phase shifter ϕ. The saturated triode P_2 gives a rectangular shape to the discharge impulse. Tube P_3 is conducting during the time in which the rectangular impulse strikes its second grid. Thus, P_3 is the electronic contact between the circuit in which the unknown current wave flows and the measuring instrument. For the sake of greater sensitivity a filter (R_3C_3) and one or two amplifier tubes (P_4) are interposed between contact tube (P_3) and instrument (A_2).

The wave analyzer measures points for the voltage across resistor R_3 in series with the discharge chamber D, thus measuring the discharge current. As a protecting device, and in order to keep the inner grid voltage of P_3 small throughout the cycle, a voltage divider R_M, with a glow lamp L in shunt, is provided. The glow-lamp shunt is set to keep the grid potential below 10 volts. This precaution, together with frequent control of the characteristic of P_3, is necessary to insure that the residual currents measured are actually flowing in the discharge gap and are not simulated by gas currents in P_3. With the wave analyzer connected in the manner described, it was possible to measure currents as low as 10^{-5} amp. in a 50-ohm resistor (R_4) to which the instrument

[10] H. Klemperer, *Rev. Sci. Inst.*, 10, 69, 1939.

was connected for 25 microseconds (about $\frac{1}{2}$ of an electrical degree) during each cycle. Because of the proximity of the individual points measured, no attempt was made to mark these points in the sketches of the current wave-form, Fig. 2, Figs. 4*a* and 4*b*.

FIG. 2.



Voltage, current, and stroboscopic appearance of discharge for different currents. Air at atmospheric pressure, and a gap length of 1 mm.

Voltage curves were obtained with the cathode-ray oscillograph (*CRO*) connected as in Fig. 1. The oscillograph shunt (R_0) was a 10^7 ohm Xylol resistor. This shunt was disconnected while current-wave points were taken.

A few characteristic wave shapes of residual currents in air at atmospheric pressure, obtained with the wave analyzer, together with sketches of stroboscopic views and corresponding voltage waves, are shown in Fig. 2. These sketches and curves connect the residual current waves, for several values (r.m.s.) of discharge current, to their respective voltage waves and to the simultaneous appearance of the gap when viewed through a mechanical stroboscope. For a discharge current of 50 ma. the principal discharge is a high-pressure glow, evidenced by a glowing skin over the electrodes and a voltage drop of the order of 300 volts. This glow exists for currents

FIG. 3.

High speed pictures of reignition. Current—0.9 amp. r.m.s., 3 mm. gap and atmospheric pressure in air (Western Electric high speed camera). Time zero arbitrarily chosen.

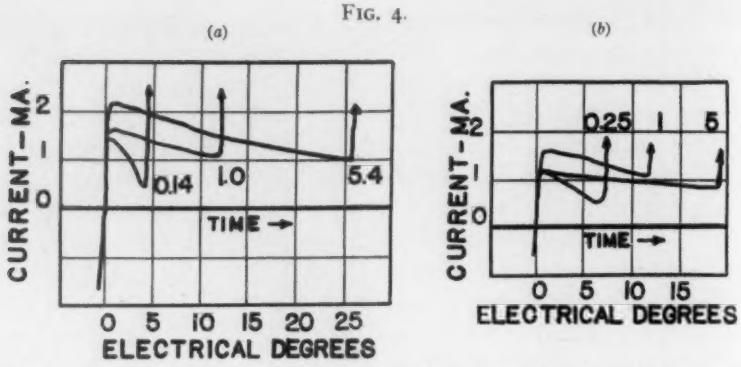
up to 0.1 amp. at atmospheric pressure and up to about 0.2 amp. at 5 atmospheres.[5] In this glow region, as Fig. 2 shows, no residual current is detected by the wave analyzer. There is also no trace of glow or luminosity visible in the gap during the period of zero current and the reignition voltage is equal to the spark-breakdown voltage. For increased discharge current of 0.1 amp. r.m.s., a residual current appears after the voltage reverses. This residual current rises to a maximum of 0.8 ma. and then decays with a time constant of about 10 electrical degrees, or 0.5 milli-second, to a constant value of about 0.3 ma. which is maintained until the discharge strikes anew. The reignition occurs at about 90 per cent. of the sparking voltage under this condition and starts by establishing a glow discharge. This glow is of random duration and changes intermittently into an arc. During the pre-ignition period there is a faint luminosity in the gap, if viewed in complete darkness. This luminosity [11] is accompanied by frequent bright scintillations, probably due to combustion of loose graphite dust particles.

When the r.m.s. current is 1 amp., Fig. 2 shows that the residual current has increased to a maximum of 2.8 ma. In this case reignition takes place at about 55 per cent. of the sparking voltage and the arc develops without a preliminary glow stage. The discharge path is constricted into a narrow column and the arc drop is of the order of 50 volts. Examination of the electrodes through the stroboscope disc indicated that there were no hot spots during the flow of residual current. The faint residual luminosity is more intense as the r.m.s. current is increased and there are frequent sparks. Finally, at 2 amp. r.m.s. the electrode tips get hot, the pre-ignition period disappears, and the voltage and current reverse without visible delay. A series of pictures showing the luminescence in the arc gap, preceding, during and following reignition (a speed of about 1680 pictures per second and exposures of 1/5000 of a second, F2 lens opening) is presented in Fig. 3.

An additional series of residual current waves is presented in Figs. 4*a* and 4*d*, both figures being taken for a representative

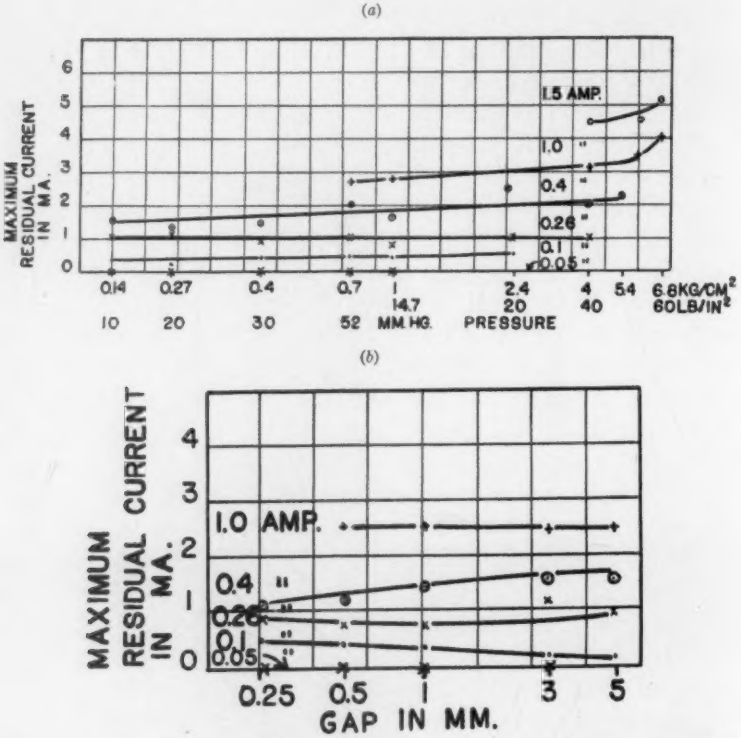
[11] B. W. Bradford and G. I. Finch, *Chem. Soc. J.*, 1, p. 360, 1934.

FIG. 4.



Residual currents at 0.4 ampere r.m.s. (*a*) Pressures of 0.14, 1.0, 5.4 atmospheres and 1 mm. gap. (*b*) Gap length of 0.25, 1, 5 mm. and atmospheric pressure.

FIG. 5.



Maximum residual current for different arc currents as functions of (*a*) different pressures for 1 mm. gap and (*b*) different gap lengths and 1 atmosphere. (Point symbols are consistent wherever used.)

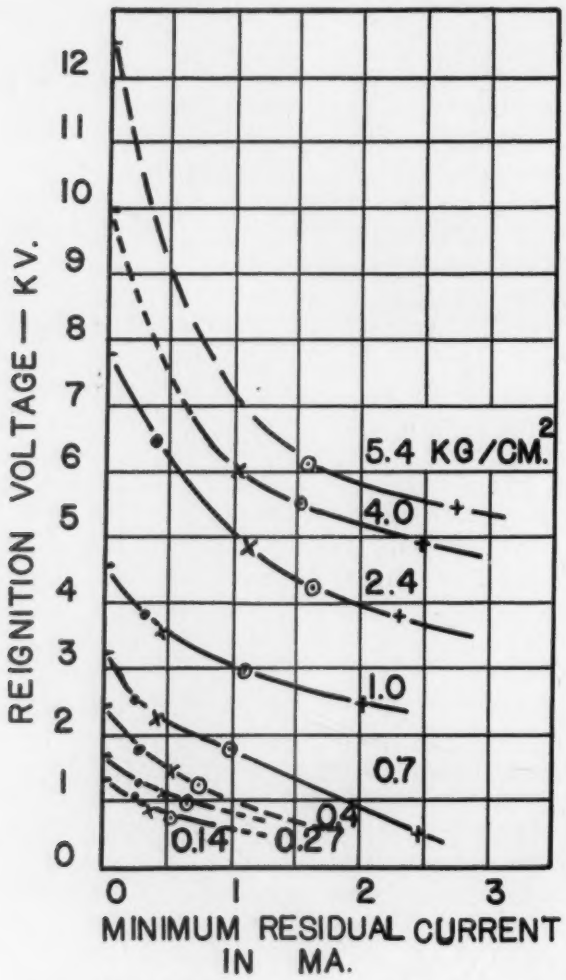
current of 0.4 amp. Fig. 4*a* shows the residual currents for a constant gap of 1 mm. and three widely different pressures (0.14, 1, 5.4 atmospheres). In Fig. 4*b* the residual currents for constant (atmospheric) pressure are given for three different gap lengths ($\frac{1}{4}$, 1, 5 mm.). Obviously, at low pressure and short gap length, the time constant of the decay of ionization is smaller than for the higher pressure and longer gap. Apparently, for such short gap lengths, deionization at the electrode surfaces plays a predominant part in causing deionization.

The effect of gas pressure and of the gap length upon the "initial" or peak-intensity of the residual current are shown in Figs. 5*a* and 5*b* for various r.m.s. values of discharge current. These curves show that the initial intensity of the residual current is very nearly independent of both gap length and gas pressure. The curves indicate further that the initial value of the residual current is directly dependent on the current of the preceding discharge. The transition between the high-pressure glow discharge and the arc discharge with a "field" type cathode, occurring between 50 and 100 ma. r.m.s. is marked by the appearance of a residual current. At the other end of the current range, between 1 and 2 amp., there is the transition from a "field"-type cathode to a thermionic cathode.[5] This is accompanied by a reversal of current without the formation of a preignition period. Reignition of the a.c. arc occurs at spark-breakdown potential if there is no residual current left over from the arcing period; otherwise the breakdown voltage is lowered. This reduction of breakdown voltage as a function of preceding arc current has been discussed before.[5,7,9] It has been shown above that in the described test set-up the initial peak of the residual current is almost a linear function of the preceding arc current (Figs. 5*a*, 5*b*). The reduction of breakdown voltage, however, does not depend primarily on this initial peak but is influenced by the final value of the residual current after the reignition period has elapsed. During this reignition period, the residual current may have increased or decreased depending on the different counteracting effects in the discharge space, as for instance, cooling effects, rising field strength, or chemical processes. Before discussing possible

reasons for the residual current's decreasing in the presence of an increasing voltage, it is well to consider the connection between breakdown and reignition potential and the final value of residual current, shown in Figs. 6*a* and 6*b* for different pressures and for different gap lengths. In these curves the

FIG. 6.

(*a*)



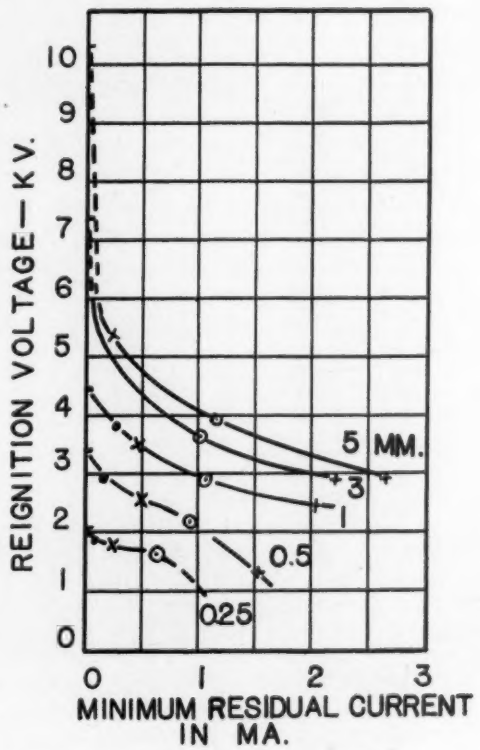
Reignition voltage for different arc currents as functions of (*a*) different

spark-breakdown voltage is indicated by points for zero residual current. The spark-breakdown voltage was obtained by slowly increasing the a.c. voltage applied to the gap. The percentage reduction in reignition voltage from the spark-breakdown value is greatest for the *p.d.* (pressure times gap length) conditions requiring high voltages. This is reasonable since the speed of the residual charged particles is higher at high voltages and the number of ionizing collisions is correspondingly greater.

It is interesting to examine the experimental results for *p.d.* similarities for the range covered. This examination reveals that both the sparking voltage and the reignition

FIG. 6.

(*b*)



pressures for 1 mm. gap; (*b*) different gap lengths for 1 atmosphere.

voltage depart from a true *p.d.* similarity relation. Since the gap is between rods with sharp edges, it is obvious that any change in gap length involves a marked change in the electrostatic field and violates, therefore, the basic requirement of the similarity law even for the sparking voltage. The added departure of the reignition voltage from similarity is to be expected from the space charge distortion, altered conductivity, and altered gas density, produced by the previous current and its residuals.[12]

In most of the tests presented here the residual currents *decrease* in the presence of a rapidly increasing recovery voltage. This means that the preignition discharge is not a normal glow discharge with conductivity due chiefly to electron impacts. We have to exclude the rising field as determining factor of the shape of residual current and have to look for effects that reduce column conductivity. Notably, column conductivity in the arc at higher pressures is maintained by thermal ionization.[13] During the reignition period the column is cooling with a gas time constant [13] of the order of 10^{-3} sec. Accordingly, the degree of ionization of the column decreases as required by Saha's equation.* But still the observed ionization is larger and the rate of decay much smaller than would be expected. We have to consider the combustion of electrode graphite as an additional source of heat in the column.† Stroboscopic views show the slight preignition glow continuously accompanied by bright scintilla-

[12] These factors were pointed out in a paper presenting a *p.d.* similarity over a relatively small gap range. J. D. Cobine, R. B. Power, *Jour. Appl. Physics*, 8, 287, 1937.

[13] C. G. Suits, *Gen. Elect. Rev.*, 39, 194, 1936.

* If a thermal time constant of 10^{-3}, and a gas pressure of 1000 mm. Hg is assumed for an arc column in air, the temperature of the column 20 electrical degrees after extinction is approximately 2000° K. The degree of ionization for this temperature is, by Saha's equation, approximately 2.7×10^{-15}. This is about 100 times the degree of ionization of normal air and the reignition voltage should be lower than the spark-breakdown value even for this long delay.

† The loss of graphite was measured and found to be 58.10^{-6} g./sec. with an arc of 0.4 amps. (r.m.s.) burning across a 1 mm. gap. Assuming an arc column of 1 mm. in diameter and an approximate gas temperature of 3500° K. during preignition period, the temperature increase of the column due to combustion comes out at $2.4 \cdot 10^{4}$°/sec., which is about 6 per cent. of the cooling speed of the arc column during preignition period.

tion, probably due to combustion of loose graphite particles which are sputtered during the period of high field strength. Tests which were carried out in air between copper electrodes, as well as other tests in nitrogen between the same graphite electrodes, showed not only a higher reignition voltage [5] but also a great decrease in residual current.

ACKNOWLEDGMENT.

The authors are indebted to Professors H. E. Clifford, E. L. Chaffee and R. Rüdenberg for valuable suggestions and to Mr. L. P. Winsor for valuable help. The Associates of the Physical Sciences of Harvard University generously provided funds for the purchase of the High Speed Camera.

Marsh Buggy for Use in Gulf Coast Fields.—H. F. SIMONS. (The Oil and Gas Journal, Vol. 38, No. 41.) Many of the oil and geophysical companies operating in the Gulf Coast areas, where swamps abound presenting transportation difficulties, have not been satisfied with being balked by nature. This has led to the development of the "marsh buggy," a truck or conveyance which can carry a heavy load over hard or soft ground or through water. After examining the methods used by other seismograph parties, the Stanolind Oil Co. has developed a marsh buggy which will travel with equal ease in water or on land. After it has finished work in a particular area, it can be disassembled into three parts and carried to the scene of its next operation on a truck. This buggy has four wheels but they are also pontoons, being made from sheet steel and hollow on the inside except for bearings and braces. Each wheel has a drain plug and a plug for greasing the bearing. All of the wheels are 4 ft. wide at the axle although the back ones are tapered to 3 ft. in diameter at their circumference. The wheels are 9 ft. in diameter, the front ones being equipped with lugs made from 4 in. angle irons for driving and the back ones having an arched surface with a steering rim on them. The Stanolind marsh buggy is 21 ft. overall in length and 15 ft. in width; the wheels, frame, motor and transmission weigh approximately 9,000 lb. It will carry a useful load of 6,000 lb. when it is put in service. Despite its weight it will climb hills, travel at 15 m.p.h. on land and approximately the same speed through water, regardless of depth. Steering on land and shallow water is through the back wheels. In the water the front wheels are used to steer. It is extremely maneuverable in both.

R. H. O.

SOME EFFECTS OF VARIABLE EXCITATION ON SYNCHRONOUS MOTOR OSCILLATION.

BY

JOHN GRIFFITHS BARRY, Ph.D.,

Bartol Research Foundation of The Franklin Institute.

ABSTRACT.

In this paper are presented the results of a study of synchronous motor oscillations resulting from sudden application of mechanical load. By means of the Differential Analyzer at the Moore School of Electrical Engineering of the University of Pennsylvania, theoretical synchronous machine equations were solved for conditions of suddenly applied load, and the effect on the resulting oscillations of variations in field excitation was determined for the most practical cases. The analyzer results were checked by a number of experimental observations, and it was found that the magnitude and duration of the oscillations could be greatly decreased by using the proper type of excitation variation.

NATURE OF INVESTIGATION AND CONCLUSIONS.

Ever since Doherty and Nickle [1, 2] and Park [3, 4] developed the mathematical treatment of Blondel's two-reaction theory, considerable interest has been evidenced in the solution of analytical equations for synchronous machine performance. The recent construction of large differential analyzers has provided means for solving the equations more readily without resorting to the laborious step-by-step processes otherwise necessary in complicated cases and has thereby reduced the number of simplifying assumptions required. The present investigation was made through the use of the differential analyzer at the Moore School of Electrical Engineering of the University of Pennsylvania, and consists of a study of the rotor oscillations resulting from sudden application of mechanical load to a synchronous motor connected to an infinite bus, together with a study of the damping effect of variations in field excitation.

The analytical equations used in this work are derived from the mathematical theory of Park,[4] and therefore embody all of Park's fundamental assumptions.[3, 4] Furthermore, the synchronous motors involved are assumed to have only a

main field winding in the direct axis and an amortisseur winding in the quadrature axis, in addition to the armature winding, as was assumed by Nickle and Pierce.[6] Several other minor mathematical approximations were made (see appendix), but the effect of armature resistance was considered in all cases, a factor usually not taken into account. For a number of cases, experimental observations were made and were found to be in good agreement with the theoretical results.

From a study of the oscillations of several typical machines, the following general conclusions are drawn:

Machines whose constants are within the usual ranges are inherently very stable under sudden application of load, and tend to remain in synchronism if the applied load is less than the maximum steady-state limit.

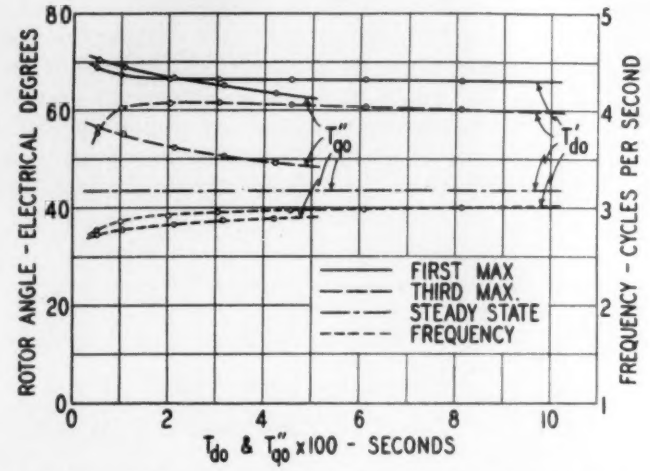
The oscillations resulting from sudden application of load can be greatly damped by proper variation of the excitation voltage. For the most practical case of rectangular variation, the frequency of variation should be very nearly the frequency of the natural rotor oscillations, and the fundamental of the rectangular wave should be opposite in phase to the rotor swings about the average rotor position.

EFFECT OF MACHINE CONSTANTS.

The results described in this and the following section were obtained by the differential analyzer solution of the analytical synchronous motor equations, the derivation of the equations and a description of experimental checks being given in the appendix. Curves *A* of Figs. 5 and 6 are typical of the differential analyzer solutions for the case of sudden application of load to a synchronous motor connected to an infinite bus, instantaneous load application having been found to produce the worst oscillation.

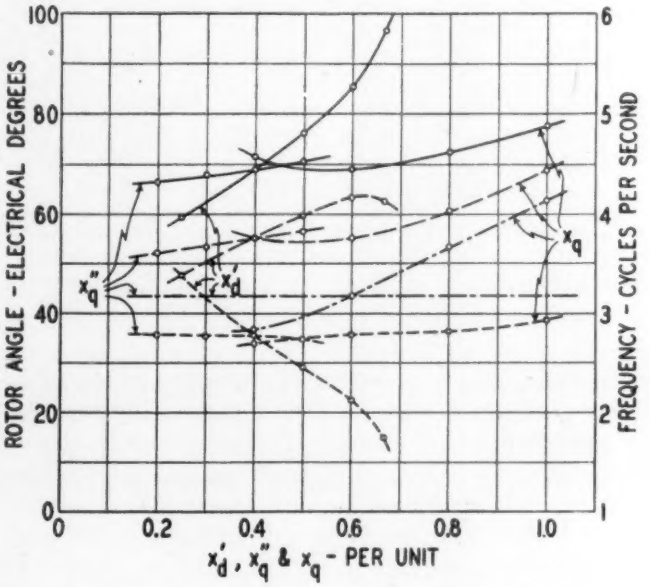
The curves of Figs. 1, 2, and 3 show the effect on the oscillations of varying separately each machine constant over a practical range of values, the other constants having the normal values given for machine A of Table I. In each case, the motor was considered to be operating at unity (per-unit)

FIG. 1.



Effect of T'_{do} and T''_{qo} on rotor oscillations of machine A. See text for conditions.

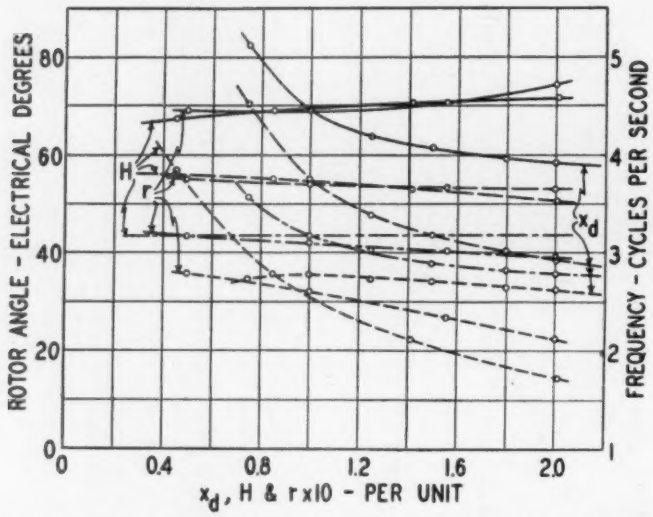
FIG. 2.



Effect of x'_d, x''_q and x_q on rotor oscillations of machine A. See Fig. 1 for curve designations.

terminal voltage and excitation, the value of applied load being 90 per cent. of the maximum steady-state limit (affected only by x_d, x_q, and r). As an indication of the magnitude and duration of the rotor oscillations, the curves show the size of the first and third maximum swings, as well as the steady-state displacement corresponding to the applied load and the natural frequency of the first two oscillation cycles, as found from the average period of the first two cycles. As

FIG. 3.



Effect of x_d, H, and r on rotor oscillations of machine A. See Fig. 1 for curve designations.

the oscillations are often very unsymmetrical about the steady-state value, it is not possible to obtain a quantity, such as the decrement factor of a damped sinusoid, that will give a reliable indication of the relative damping in all cases.

A study of the curves of Fig. 1 shows that, for greatest natural damping, as indicated by the comparative magnitudes of the excesses of the first and third maxima over the steady-state value, the direct axis time constant should be as small as possible, while for the range covered, the quadrature axis time constant should be large. Thus, it appears that the resistance of the main field should be high and that of the

quadrature axis amortisseur should be low. Increasing the direct axis time constant above two seconds seems to have little effect on the size of the oscillations, while an increase in either constant raises the natural frequency slightly.

From Fig. 2, the oscillations are seen to become larger rapidly as x'_d increases and approaches x_d, a point being reached, in fact, at which the motor drops out of synchronism on the first rotor swing for the same value of applied load. For the conditions under which the curves were obtained, there is an optimum value of x_q for which the actual swings are minimum, and also an optimum value giving maximum damping. The constant x''_q should apparently be as low as possible for the smallest swings and the greatest damping.

TABLE I.

Some Representative Synchronous Machine Constants—Per-Unit Values.

Machine	H	x_d	x'_d	T'_{do}	x_q	x''_q	T''_{qo}	r
A	0.85	1.00	0.40	0.509 sec.	0.60	0.40	0.0103 sec.	0.05
B	0.85	1.00	0.667	0.509 sec.	0.60	0.40	0.0103 sec.	0.05
C	1.513	1.00	0.40	2.035 sec.	0.60	0.40	0.0515 sec.	0.05
D	1.132	0.80	0.225	0.735 sec.	0.521	0.391	0.0159 sec.	0.0375
E	1.061	0.667	0.225	0.735 sec.	0.464	0.391	0.0159 sec.	0.0375

Figure 3 indicates that a reasonable change in r or H does not affect the size of the rotor swings very greatly, although the natural frequency decreases with increase in either of these constants. As the moment of inertia is changed, the frequency is very nearly inversely proportional to the square root of H, as should be the case for simple harmonic oscillations. The magnitude of the swings increases as x_d is reduced, but the steady-state displacement is also increased, thus accounting to some extent for the actual increase in maximum rotor angle.

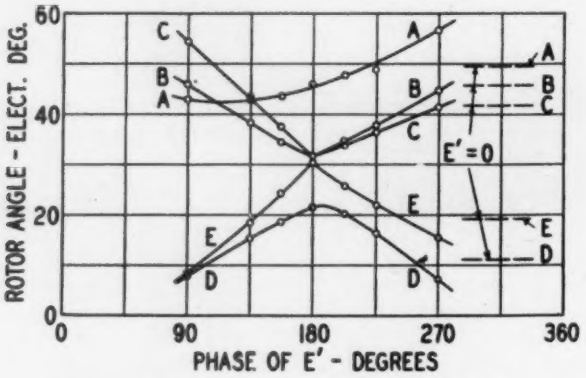
After a consideration of the range of constants likely to be found in practical synchronous motors, and after a determination of the effects of different values of the individual constants on the oscillations, as exhibited by the curves of Figs. 1–3, the sets of constants listed in Table I were selected as representing typical machines for investigation of the effects of variable excitation. Machine A corresponds to a small

average synchronous motor, while machine B is similar except for having an extreme value of x'_d. Machine C is intended to represent a fairly large motor with large moment of inertia and fairly high time constants. Machines D and E represent experimental data (to be discussed later), and are included in the table for comparison and convenience.

EFFECT OF VARIABLE EXCITATION.

As any arbitrary excitation variation whose time integral exists will produce a corresponding angle-time curve when

FIG. 4.

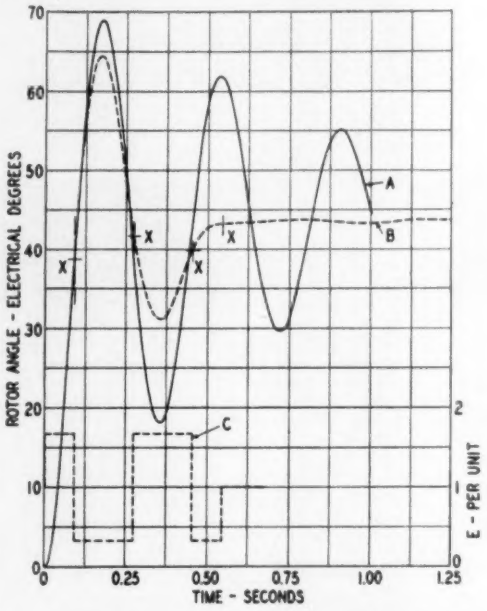


Effect of phase of E' on rotor oscillations of machine D.
$E_0 = e = 1.05$
$E' = 1.00$
$T_L = 1.00$
Freq. of $E' = 3.07$ c.p.s.
Curves A, B, and C are first, second, and third maxima, respectively.
Curves D and E are first and second minima, respectively.
Rotor swings for constant excitation ($E' = 0$) are also shown.

substituted in the analytical equations, it was desirable to select the simplest practical type of variation to be used in the investigation of damping effects. Accordingly, E', the variable part of the excitation, was taken to be a portion of a symmetrical rectangular wave with frequency equal or close to the natural frequency of the rotor oscillations for the case under consideration, the excitation being abruptly changed to the appropriate value on the rectangular wave upon load application, and returned to normal after a definite time interval, as illustrated by curve C of Fig. 5. The optimum phase angle between the fundamental of the rectangular

excitation wave and the rotor oscillation was found to be 180 degrees, that is, greatest damping was found to occur when the phase is such as to make the excitation minimum when the rotor displacement is greater than average, and vice versa. The curves of Fig. 4 indicate the size of successive rotor swings as the phase of the fundamental of E' is changed with respect to the fundamental of the rotor oscillation about the average

FIG. 5.



Damping effect of varied excitation, machine A.

$E_0 = e = 1.00$
$E' = 0.667$
$T_L = 0.970$
Freq. of $E' = 2.73$ c.p.s.

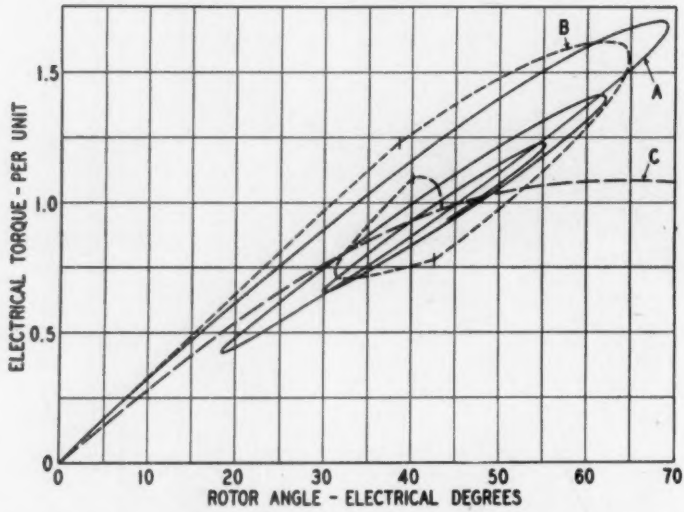
Curve *A*—Constant excitation.
Curve *B*—Varied excitation.
Curve *C*—Excitation curve.
Excitation changed at points *X* on curve *B*.

position. The 180 degree phase angle is obviously best for this case, and was also found to be best in other instances. The least final rotor oscillation was found to occur when the excitation is returned to normal at the proper instant to make the time integral of E' equal to zero. This might be expected, as if this integral is not zero, an excess amount of flux is introduced into the direct axis, requiring a greater time for the decay of transient effects.

The curves of Fig. 5 illustrate the damping effect produced by the excitation changes shown by curve *C*, the frequency and amplitude of E' being optimum. From the corresponding torque-angle curves of Fig. 6, the changes in excitation are seen to widen the loops of the transient torque-angle curve, in agreement with the idea that wider loops indicate greater damping action.

Various values of load were applied to machines A, B, and C and the excitation was varied in the manner shown by

FIG. 6.



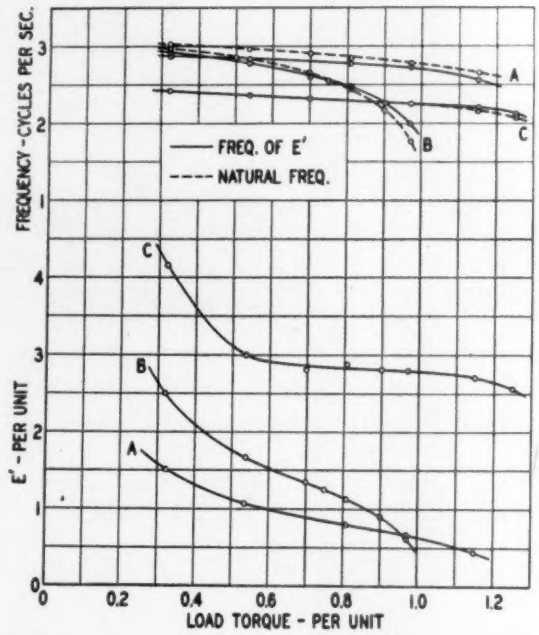
Torque-angle curves corresponding to Fig. 5. Curve *A*—Constant excitation. Curve *B*—Varied excitation. Curve *C*—Steady-state curve, from equations (18)–(20).

curve *C* of Fig. 5, the frequency and amplitude of E' being carefully adjusted to the optimum values for each case, so as to produce the complete damping exhibited by curve *B* of Fig. 5. The curves of Fig. 7 indicate the change in the optimum values as the applied load is changed, the natural frequency being also shown for comparison with the frequency of E'. In all cases the damping effect was found to be rather critically dependent on the frequency, and usually also on the amplitude, of E'.

From a comparison of the curves of Fig. 7 for machines A

and C, it is evident that an increase in the time constants and moment of inertia, roughly equivalent to increasing the size of machine, increases the amount of change in excitation required to produce complete damping. At light loads, the required amount of change increases rapidly, in line with the simplified mathematical theory presented in the appendix.

FIG. 7.



Effect of load on periodic excitation required for complete damping. Curve *A*—Machine A. Curve *B*—Machine B. Curve *C*—Machine C.

However, at light loads, the actual amount of oscillation decreases, so that complete damping is not essential. It does not appear to be practical to damp out completely the oscillations of machines having larger time constants than those of machine C, as the required range of excitation becomes excessive. Indeed, when the direct axis time constant of machine C was increased to an upper limit of 5.09 seconds, it was found that a change of 8.0 per-unit excitation was required to damp out completely the oscillations resulting from

application of 0.970 per-unit load. For all of the curves plotted in Fig. 7, the maximum steady-state load is 1.08 per-unit, although loads greater than this were successfully applied to machines A and C. In such cases, the oscillations could be almost completely damped out, but the motor could not be prevented from eventually dropping out of synchronism. A comparison of curves *A* and *B* indicates that increase in x'_d causes the required amplitude of E' to be greater at light loads, but the initially higher value drops off more rapidly as the load is increased.

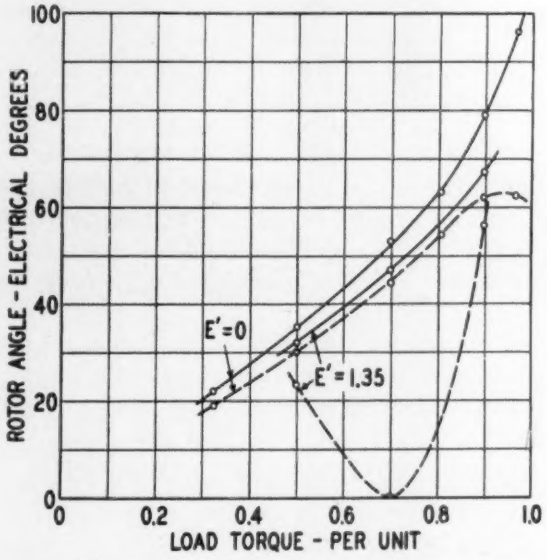
The frequency curves of Fig. 7 indicate that the optimum frequency of E' is very nearly the same as the natural frequency for machine C, but is somewhat different for the other machines. Methods for calculating natural frequencies of *small* oscillations have been presented by other authors, but the accuracy for large oscillations is doubtful, especially for the application of loads greater than the steady-state maximum, when the steady-state displacement angle is meaningless. However, the limiting frequency which the curves of Fig. 7 approach at no-load should be possible of calculation by conventional methods, as the oscillations approach zero amplitude at no-load.

In order to determine the practicability of using a fixed variation in excitation over a range of loads, the curves of Fig. 8 were obtained. The amount of change in excitation and the frequency of this change required for complete damping at 0.7 load were used at 0.5 and 0.9 load, with the result indicated. For this range of load, the variation in excitation reduces the magnitude of the rotor swings below the value that would be obtained with no variation, although the swings increase rapidly as the load is changed from the optimum value. As the excitation curves of Fig. 7 are not as steep for machines A and C as for machine B, it is to be expected that greater damping can be obtained over a wider range of load with a fixed change in excitation in the case of the former machines.

The investigation described in this paper indicates that the rotor oscillations of synchronous motors can be greatly damped by the proper use of periodic excitation variations, the range of excitation required being reasonable if the direct

axis time constant is not too great. Although the change in excitation was always initiated at the time of the load application, yet the results indicate that considerable damping can be obtained when the variation starts after the load application, provided the frequency and amount of change are properly chosen. At least one practical application of periodic excitation to a synchronous motor would be in the

FIG. 8.



Use of a fixed change in excitation over a range of loads, machine B. First and third maximum swings are designated as in Fig. 1.
$E_0 = e = 1.00$
$E' = 1.35$
Freq. of $E' = 2.62$ c.p.s.

case of a periodically recurring load that would cause dangerous cumulative oscillations to be built up if allowed to continue. By damping out the oscillations after each application of load, cumulative increase could be prevented. The results of this investigation also indicate that the use of periodic excitation would provide considerable aid for pulling motors into step when starting and synchronizing, or for almost any case where a periodic internal torque can be used to counterbalance some periodic external disturbance. For the best use of periodic excitation, saturation effects should

be small, and hence specially designed motors might be required for cases involving large changes in excitation. By supplying the excitation from grid-controlled rectifiers, variations of the proper amplitude and frequency could be most readily obtained for any actual operating conditions.

NOMENCLATURE.

In the presentation of the analytical equations, standard nomenclature is used where possible. All constants are expressed in the per-unit system, based on the nominal kva. rating and terminal voltage of the synchronous machine, except as noted in the following table:

x_d	Direct axis synchronous reactance of armature.
x'_d	Direct axis transient reactance of armature.
x_{afd}	Mutual reactance between armature and field (direct axis).
$x_d(p)$	Impedance operator associated with i_d in the expression for the direct axis flux linkages.
x_q	Quadrature axis synchronous reactance of armature.
x''_q	Quadrature axis subtransient reactance of armature.
$x_q(p)$	Impedance operator associated with i_q in the expression for the quadrature axis flux linkages.
$G(p)$	Impedance operator associated with E_{fd} in the expression for the direct axis flux linkages.
r	Resistance of the armature winding.
R_{fd}	Resistance of the main field winding (direct axis).
i_d	Direct axis component of armature current.
i_q	Quadrature axis component of armature current.
ψ_d	Flux linkages with the armature in the direct axis.
ψ_q	Flux linkages with the armature in the quadrature axis.
e	Voltage of infinite bus.
E_{fd}	External voltage in the field circuit.
E	Excitation or field voltage expressed in such a way that when E is unity, rated terminal voltage (armature) is developed on open circuit under steady-state conditions. Note that $E = (x_{afd}/R_{fd})E_{fd}$.
E_o	Constant component of E.
E'	Variable component of E, so that $E = E_o + E'$.

T'_{do} Time constant of the main field with the armature open circuited (expressed in electrical radians).

T''_{qo} Time constant of the quadrature axis amortisseur winding with the armature open circuited (expressed in electrical radians).

H Inertia constant of rotor = $(0.231 \times I \times \text{r.p.m.}^2)/(10^6 \times \text{base kva.})$, where I is the conventional moment of inertia expressed in lb.-ft.^{2}.

f Rated frequency in cycles per second.

t Time expressed in electrical radians, one radian being the time required for the rotor to describe one electrical space radian at rated speed.

δ Angular displacement of the rotor with respect to the infinite bus, measured in electrical space radians.

p The operator d/dt.

T_e Electrical torque acting on the rotor.

T_L Mechanical torque absorbed by the load.

APPENDIX.

Mathematical Relations.

From Park,[4] the following general equations are obtained for a synchronous machine connected to an infinite bus:

$$e \sin \delta = p\psi_d - ri_d - \psi_q - \psi_q p\delta, \tag{1}$$

$$e \cos \delta = p\psi_q - ri_q + \psi_d + \psi_d p\delta, \tag{2}$$

$$\psi_d = G(p)E_{fd} - x_d(p)i_d, \tag{3}$$

$$\psi_q = -x_q(p)i_q, \tag{4}$$

$$T_e = i_q\psi_d - i_d\psi_q, \tag{5}$$

$$4\pi f H p^2\delta = -T_L - T_e. \tag{6}$$

Expressions for the operators $G(p)$ and $x_d(p)$ are developed by Waring and Crary [8] for the case in which there is an amortisseur winding or other additional rotor circuit in the direct axis. When this winding is neglected, the operators can be reduced by proceeding to the limit as the resistance of the additional circuit approaches infinity. On doing this and substituting equations (20) and (27) of reference 8,

there results:

$$G(p) = \frac{x_{afd}}{R_{fd}(T'_{do}p + 1)}, \tag{7}$$

$$x_d(p) = \frac{x'_d T'_{do}p + x_d}{T'_{do}p + 1}. \tag{8}$$

Substitution of (7) and (8) in (3) gives

$$T'_{do}p(\psi_d + x_d i_d) = -\psi_d - x_d i_d + (x_{afd}/R_{fd})E_{fd}. \tag{9}$$

It is seen that the last term on the right hand side of (9) represents the steady-state open circuit terminal voltage corresponding to the field voltage E_{fd}. Hence, this term can be replaced by the field excitation E, unity value of E being that field voltage giving rated terminal voltage on open circuit at steady-state. This substitution is merely equivalent to changing the base of the per-unit field excitation. On integrating (9) after making this change, there results

$$\psi_d = -x'_d i_d - \frac{1}{T'_{do}} \int (\psi_d + x_d i_d - E)dt. \tag{10}$$

In an analogous manner, the quadrature axis equation is obtained, namely

$$\psi_q = -x''_q i_q - \frac{1}{T''_{qo}} \int (\psi_q + x_q i_q)dt. \tag{11}$$

Equations (1), (2), (5), (6), (10), and (11) are the fundamental equations for the synchronous machine connected to an infinite bus. These equations hold for either generator or motor action, the rotor angle and electrical torque being negative for the latter case (positive load torque).

It was found most expedient to neglect the terms $p\psi_d$, $p\psi_q$, $\psi_d p\delta$, and $\psi_q p\delta$ in equations (1) and (2), as inclusion of these terms would necessitate the use of the inherently inaccurate processes of manual differentiation, multiplication, and input, due to the limitations imposed by the physical size of the differential analyzer. As the terms involved were found to be relatively small in a number of cases, and as numerous idealizing approximations were made in the original derivation of the equations (saturation effects were neglected,

for instance), the additional approximations were considered to be justified. Accordingly, the following equations are those finally used with the differential analyzer:

$$e \sin \delta = - ri_d - \psi_q, \tag{12}$$

$$e \cos \delta = - ri_q + \psi_d, \tag{13}$$

$$\psi_d = - x'_d i_d - \frac{1}{T'_{do}} \int (\psi_d + x_d i_d - E) dt, \tag{14}$$

$$\psi_q = - x''_q i_q - \frac{1}{T''_{qo}} \int (\psi_q + x_q i_q) dt, \tag{15}$$

$$T_e = i_q \psi_d - i_d \psi_q, \tag{16}$$

$$4\pi f H \frac{d^2\delta}{dt^2} = - T_L - T_e. \tag{17}$$

Under steady-state conditions of operation, the integrands of (14) and (15) become zero, as well as the left hand side of (17), the other equations of the group remaining unaltered. On solving the steady-state equations for i_d and i_q and expressing the torque in terms of these currents, there results

$$i_d = \frac{1}{x_d x_q + r^2} [- e(r \sin \delta + x_q \cos \delta) + x_q E], \tag{18}$$

$$i_q = \frac{1}{x_d x_q + r^2} [e(x_d \sin \delta - r \cos \delta) + rE], \tag{19}$$

$$T_L = - T_e = i_d i_q (x_d - x_q) - i_q E. \tag{20}$$

From these last three equations, the conventional steady-state torque-angle curves can be plotted, taking armature resistance into account. When the latter is neglected, the above equations reduce to equation (54) of reference 1.

At no-load (steady-state), the rotor displacement is known to be small, and hence the sine of the angle can be replaced by the angle itself and the cosine by unity. Then, from (18)–(20), there is obtained for $T_L = 0$

$$\delta = \frac{r}{x_d} \left(1 - \frac{E}{e} \right). \tag{21}$$

This equation shows that the no-load steady-state rotor angle is zero if the resistance is zero, or if the excitation is equal to the terminal voltage. The no-load values of the other quantities can be readily found by substituting (21) in the steady-state equations mentioned above.

When, as a further approximation, the quadrature axis amortisseur winding is assumed to be open circuited ($T''_{qo} = 0$), and when the armature resistance is neglected, equations (12)–(17) reduce to

$$4\pi fH\frac{d^2\delta}{dt^2} = -T_L - \left\{ e^2\left(\frac{1}{x_q} - \frac{1}{x'_d}\right)\sin\delta\cos\delta + \frac{e\sin\delta}{x'_d T'_{do}}\int(\psi_d + x_d i_d - E_o)dt + \frac{e\sin\delta}{x'_d T'_{do}}\int E'dt \right\}. \quad (22)$$

In equation (22), the second term in the brackets on the right hand side represents the normal damping effect of the current induced in the main field winding, while the third term represents the damping torque produced by the change in excitation. From the multiplying factors, it is evident that the total damping effect should be small at light loads, when the sine of the displacement angle is never very large, and should also become less as the direct axis time constant is increased. These conclusions are in agreement with the curves of Fig. 7, from which it was observed that a greater change in excitation is required for complete damping at light loads, and also at all loads when the direct axis time constant is high. In spite of the non-linearity of equation (22), it is evident that the frequency of E' should be the same as that of the resulting oscillations, and the phase should be such as to make the last term in the brackets oppose the rotor acceleration, if the greatest damping effect is to be produced. Hence E' should be positive when the acceleration is negative, and vice versa, but as the acceleration is zero at approximately the same time that the rotor passes through its average position and as the rotor angle is essentially negative for motor action, this condition means that E should be minimum while the rotor displacement is maximum, and vice versa, as found by the use of the analyzer.

Experimental Results.

In order to obtain an experimental check on the results found by solution of the analytical synchronous motor equations, a number of observations were made on the performance of a synchronous machine in the laboratory of the Moore School. The machine selected was a G. E. Co. a-c. generator Type ATI-6-37.5M-12—Form PE having salient poles and a rotating field structure equipped with an amortisseur winding. This machine was connected to have a nameplate rating of 37.5 kva., 30 kw., 220 volts, 98 amps., three phase Y, 60 cycles, 1200 r.p.m., and was operated from the a-c. mains as a synchronous motor, a direct connected 40 hp., 110 volt d-c. machine being used as a mechanical load.

The angle-time curve of the laboratory motor was obtained by subtracting out the constant synchronous component from the rotational speed by using a small reference synchronous motor and differential gear. The differential gear output, an indication of the oscillatory component of the motor speed, was used to vary the balance of a Wheatstone's bridge having an oscillograph element in the galvanometer position. Mechanical load was applied to the a-c. motor by closing a contactor in the armature circuit of the separately excited d-c. machine, the load build-up (considering the mechanical load to be proportional to the square of the d-c. current) being sufficiently rapid to be taken as instantaneous, as found from a comparison of analyzer results for true instantaneous application and for the actual application. Sudden variations in the excitation voltage of the synchronous motor were produced by short circuiting one or more exciting generators in the field circuit. For periodic variations, a rotary drum switch was constructed to give the proper switching sequence and was synchronized with the load applying contactor and the oscillograph controls.

The constants of the laboratory motor were measured experimentally according to the methods outlined by Wright.[10] Saturation effects were found to be rather large where a comparison of values obtained at different degrees of saturation was possible. The constants of machine D of Table I are the test values corresponding to a moderate amount of saturation, the tabulated inertia constant including the inertia

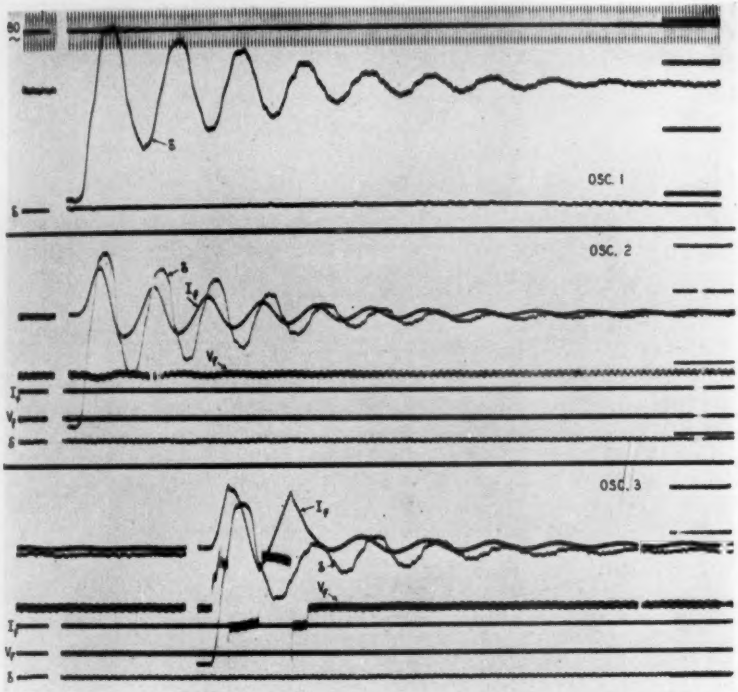
of the d-c. machine. Experimental determinations of the natural frequency were made for certain conditions, and the steady-state torque-angle curves were obtained for normal and for one-half excitation, the mechanical torque being found from the net electrical input, exclusive of resistance loss. However, the experimental frequency was somewhat higher than the analyzer frequency for the same conditions for machine D, and the theoretical steady-state torque-angle curves were found to lie below the corresponding experimental curves. In view of these discrepancies, the values of x_d and x_q were adjusted to give the best average agreement between the theoretical and observed torque-angle curves, and the value of H was adjusted to produce the best agreement in frequency, the adjusted values being those of machine E of Table I. The changes made in the values of the constants did not seem excessive, in view of the possible experimental errors of measurement, and particularly in view of the effect of saturation on the measured reactances.

When the constants were adjusted as described, the frequency of oscillation as found by the analyzer for application of full load at normal voltage and excitation was in very good agreement with the observed frequency for the same conditions, but the theoretical machine (E) did not seem to drop out of synchronism as fast as the actual machine upon application of full load at half excitation, under which condition full load could not be carried at steady-state. By adjusting all of the constants, better agreement could probably be obtained, but in any case, perfect agreement can hardly be expected, because of the physical approximations made in deriving the basic equations. In addition, it is probable that some external damping was introduced by the d-c. machine in the experimental case.

Oscillogram No. 1 of Fig. 9 was obtained for application of approximately full load to the synchronous motor at normal voltage and excitation, the actual applied load being such as to make the final value 0.994 per-unit, there being an initial load imposed by mechanical losses in the a-c. and d-c. machines. The oscillogram shows the rotor angle-time curve following the load application, the irregularities in the curve being caused by mechanical vibration of the angle indication

device previously described. Oscillogram No. 2 is similar to No. 1, except that No. 2 shows the field current and voltage waves in addition to the angle-time curve, the rapid fluctuations in field voltage being due to commutator ripple in the exciting generators. Oscillogram No. 3 was obtained for

FIG. 9.



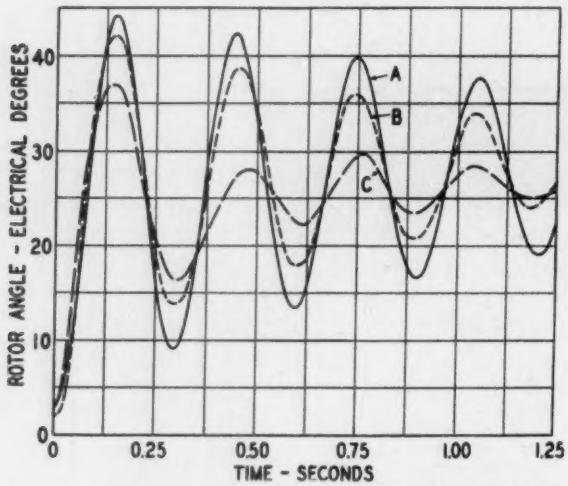
Some experimental oscillograms. Oscillograms No. 1 and No. 2—Full load applied at $E = e = 1.05$. Oscillogram No. 3—Full load applied at $E_0 = e = 1.05$, E varied from 1.32 to 0.78. δ is rotor angle, If is field current and Vf is field voltage.

application of approximately the same amount of load under the same conditions as for No. 1, but with the load application followed by periodic variation of the excitation voltage from 1.32 to 0.78 about a mean value of 1.05 per-unit, this being the greatest change that could be made with the available apparatus because of the excessive field current required to overcome saturation at the higher values of excitation. The

frequency and phase of the change in excitation have the optimum values previously determined by the analyzer for machine E under the given conditions. The variation in field voltage was intended to be rectangular, but arcing at the contacts of the switching apparatus produced the departures seen to exist.

Curve *A* of Fig. 10 was obtained by the analyzer for application of 0.901 per-unit load to machine E at 1.05 per-unit voltage and excitation, 0.099 per-unit load being already

FIG. 10.



Comparison of analyzer and experimental curves. Curve *A*—Analyzer curve, machine E. Curve *B*—Plot of oscillogram No. 1. Curve *C*—Plot of oscillogram No. 3.

carried by the motor at steady-state. Curve *B* is plotted from oscillogram No. 1, and curve *C* from oscillogram No. 3. A comparison of curves *A* and *B* shows that the analyzer result is somewhat pessimistic, as the actual oscillations are smaller and decrease more rapidly than those obtained theoretically. Curve *C* indicates that considerable damping effect is produced by even a relatively small change in the excitation voltage of the actual machine. On the whole, the agreement between theoretical and experimental results is rather good, considering the approximations necessary in the derivation of

the theoretical equations and the difficulties incident to the procurement of the experimental results.

Effect of Increased Excitation.

In addition to the investigation of the effects of periodic variations in excitation previously described, a study was made of the effect of a simple increase in excitation on machines D and E. Full load was applied at normal voltage, but at reduced excitation, and the effect of increasing the excitation at various time intervals after the load application was determined by the analyzer and by experiment. It was found that the machines considered are very stable and tend to remain in synchronism during the first few rotor swings, eventually dropping out of synchronism only if the applied load is greater than the maximum steady-state limit. In fact, it was concluded that the transient stability of these machines is determined entirely by the ability of the machine in question to carry the applied load under steady-state conditions, and the only effect of increased excitation is that incident to raising the steady-state load. If such increase in excitation should be made before the rotor displacement becomes too great, the rotor will return fairly rapidly to the steady-state angle determined by the new value of excitation, with little resulting oscillation. The theoretical results determined by the use of the analyzer were checked very well qualitatively by experiment, there being of course some quantitative differences in magnitude, the experimental oscillations being smaller than the theoretical ones.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

PERFORMANCE TEST OF FLOOR COVERINGS.

In an effort to determine within a comparatively short time the relative ability of various types of floor coverings and various methods of installation to withstand hard and prolonged service, a performance test, necessarily somewhat severe, has been conducted in the Bureau's floor-testing chamber. This work formed part of the research program on building materials suitable for low-cost house construction. As explained in the complete account of these experiments, published as Building Materials and Structures Report BMS34, uncontrolled variations in many important factors such as quality of materials used, condition of subfloors, methods of installation, and extent of abuses make direct comparisons of floor coverings in service a difficult matter.

The floor-testing chamber contains a circular track 4 ft. wide and approximately 40 ft. in diameter, in which are installed wood or concrete subfloors and the various floor coverings and adhesives for test. In the performance test, a platform truck equipped with steel wheels was propelled around the track by a "walking wheel" 4 ft. in diameter. The walking wheel was shod with leather during the first half of the test and with abrasive cloth during the second half. The floor coverings tested included several kinds of linoleum, felt-base floor coverings having various wearing surfaces, pressed fiberboard, and three strip wood floors. The bonding agents used included lignin pastes, resinous cements, casein-latex cement, asphaltic cements, and nails.

The results of the performance test have been judged principally by the general appearance of the installations at the end of the test, after 48,000 cycles of the testing equipment. Representative photographs of the different floor coverings at the end of the test are shown.

* Communicated by the Director.

In the selection of a floor covering and bonding agent, the nature of the service to which they will be subjected and their cost should be considered along with the desires of the user with respect to specific properties. Some of the lower cost floor coverings and methods of bonding, even though less durable, may render economical and satisfactory service, provided they are not subjected to abuse and only moderate length of service is required, or where frequent replacements may be desirable, such as in rental dwellings. When durable floor coverings are used over wood subfloors under severe traffic conditions, an underlay of asphalt-saturated lining felt is recommended from the standpoint of indentation and durability. Where less durable floor coverings are used and occasional reinstallations are probable, dry lining felt in conjunction with lignin paste over wood subfloors is desirable, unless other adequate means are provided for removal.

Copies of BMS34 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

EFFECT OF HEATING AND COOLING ON PERMEABILITY OF MASONRY WALLS.

Since the coefficients of thermal expansion of masonry units and mortars are unequal, changes in temperature may cause cracks in the mortar joints of masonry walls, through which water can leak during a wind-driven rain.

Permeability tests have been made at the Bureau on eleven small masonry wall specimens before and after exposing them to a number of cycles of heating and cooling. Seven of the specimens were 12-in. brick walls, two were of clay tile with stucco facings, and two were brick walls with hollow-unit backings. The walls were dry when subjected to extremes of temperature over a range of about 105° F. The maximum air temperature was about 125° F. and the minimum less than 20° F. For each cycle, the walls were stored in the heating or cooling rooms until they attained room temperature. The results indicate that repeated exposure of dry walls to extremes of temperature does not have an important effect on the permeability of all-brick walls.

The complete account of this work has just been published as Building Materials and Structures Report BMS41. Copies are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

ELECTRICAL PROPERTIES OF MARBLE.

In the *Journal of Research* for March (RP1281), Arnold H. Scott describes a determination of the dielectric constant, power factor, and resistivity of marble from Vermont, Alabama, and Georgia. Measurements were made when the marble was dry, and after it had been stored for over a month in an atmosphere having a relative humidity of 85 per cent. The effect of frequency on the dielectric constant and power factor was also studied. It was found that the electrical properties of marble may vary widely but that the colored marbles have higher dielectric constants and power factors than the white marbles.

MEASUREMENT OF GAMMA RADIATION FROM RADIUM BY THE FREE AIR IONIZATION CHAMBER.

X-rays generated by 1,000,000 volts are now commonly used in medical treatment, and it has become necessary to extend the standards of X-ray dosage from the older limits at 400,000 volts to the newer million volt region. To this end, a 1,500,000 volt X-ray generator will be installed in the new laboratory which is nearing completion at the Bureau. As a preliminary to the use of the new equipment, it has been necessary to explore further the possibilities of the present X-ray dosage standards. One-half gram of radium was borrowed from the National Cancer Institute, to serve as a source of radiation having a penetration and quality comparable to that from 1,500,000 volt X-rays. Measurements with this radium proved the adequacy of the Bureau's standards for such measurements, and in fact, established for the first time the relationship between the international units of X-ray dosage and gamma ray dosage. Million volt X-rays and the gamma rays from radium are somewhat similar in their medical usefulness, but it has been impossible up to the

present adequately to compare the two, and to decide the relative economics of the two modes of treatment. With the newly established relationship between their respective units of dosage, which is fully discussed in a paper (RP1283) by Lauriston S. Taylor and George Singer in the March *Journal of Research*, it is believed that the range of usefulness of each will be extended.

REDUCING POWERS OF SUGARS.

In the *Journal of Research* for March (RP1282), Horace S. Isbell, William W. Pigman, and Harriet L. Frush describe a modification of Scales' method for the determination of reducing sugars. The boiling time was increased, and reducing values of 32 sugars were determined at various concentrations. The method as modified provides a simple, convenient means for the quantitative determination of the rare sugars. A comparison of the reducing values of different sugars reveals that the configurations of carbons 3, 4, and 5 have marked effect on the reducing values, but that the configuration of carbon 2 has little influence. Sugars in which the hydroxyl on carbon 3 is *trans* to the hydroxyls on carbons 4 and 5 give the highest reducing powers, while those which have *cis* hydroxyls on carbons 3 and 4 give lower reducing values. When the glycosidic union of a disaccharide is on carbon 3, the molecular reducing power is less than that of the monosaccharide corresponding to the reducing part of the molecule; if the glycosidic union is on carbon 4, the molecular reducing power is about 1.4 that of the corresponding monosaccharide, and if on carbon 6, the molecular reducing power is about 1.2 that of the corresponding monosaccharide. The effect of barium bromide on the reducing powers of the sugars varies with the experimental conditions. Under the conditions used in this investigation the presence of 6.5 per cent. of barium bromide lowers the reducing value by approximately 4 per cent.

SILVER-LINED BARRELS AND CANS.

Methods suitable for producing silver-lined barrels and cans are outlined in a paper to be published in the *Journal* of

the American Electrochemical Society. This describes the results of research work at the Bureau by the American Silver Producers' Research Project staff. The paper, entitled, "Research on Industrial Silver Plating," by A. J. Dornblatt, A. C. Simon, A. M. Setapen, G. J. LeBrasse and J. T. Lumley, discusses the production of pore-free silver deposits, the application of commercial forming operations to the manufacture of silver-lined containers by deep drawing operations, and the assembly of silver-lined barrels and fittings by silver brazing.

MATHEMATICAL TABLES.

A series of about ten publications containing mathematical tables is being prepared, under the sponsorship of the Bureau, as part of program of the Work Projects Administration. Two of these publications, bearing the following titles, are now available:

Tables of the first ten powers of the integers from 1 to 1000.
Tables of the exponential function e^x.

In any scientific or technical research, these should prove valuable for reference purposes. The editions are limited, but the Bureau has been able to place copies in the leading Government depository libraries.

Those desiring the tables for personal use can purchase them as long as the supply lasts, at 50 cents for "the first ten powers," and $2.00 for "the exponential function." In the case of copies to be sent abroad, 15 cents and 50 cents, respectively, should be added to these prices.

Checks should be made payable to the National Bureau of Standards and sent with order to the Information Section, National Bureau of Standards, Washington, D. C. Copies can not be sent collect or on approval.

Industrial Research and Changing Technology.—GEORGE PERAZICH AND PHILIP M. FIELD have made quite an extensive report as a result of their studies of conditions along these lines. The report is numbered M-4 and the work was a National Research Project of the Works Progress Administration. Among other things, the report states that statistical evidence indicates that during the period covered by this study research activities have been rapidly expanding. An analysis of the National Research Council surveys showed that between 1927 and 1938 the number of organizations reporting research laboratories has grown from about 900 to more than 1,700 affording employment to nearly 50,000 workers. Of all industries which maintain research laboratories, "Chemicals and allied products" have the largest number of employees. The group of industries covered by this classification employed over 9,500 laboratory workers in 1938. In the large industrial laboratories, whose work has become increasingly characteristic of today's research techniques, the research has itself become a mass production industry. Just as division of labor in manufacturing made possible significant increases in labor productivity, so the application of this principle to research has improved the effectiveness of the scientific work. In the attack upon a complex problem, the work in these laboratories is systematically divided among specialists in the several sciences or their branches. Each works on a separate phase of the investigation, and few need to know all the phases of the problem. The extent of the advantages which accrue to the laboratory when its size is increased, as well as the precise definition of what constitutes a large laboratory, may vary considerably from one industry to another depending on the character of the process and product, the size of enterprises in the industry, and the diversity of products. One feature which characterizes today's industrial research is that it represents a planned effort to achieve a solution of various industrial problems. The problems to be investigated and, to some extent, the ends sought are determined according to the business policies of the management.

R. H. O.

THE FRANKLIN INSTITUTE.

THE FRANKLIN INSTITUTE AND THE AMERICAN PATENT SYSTEM, 1790–1940.

During the Seventeenth Century it was customary for the Colonies to grant its citizens protection for discoveries and inventions. The first patent of which there is any record was issued by the colony of Massachusetts Bay, to Samuel Winslow, on April 2, 1641, for the manufacture of salt. It was not until after the adoption of the Constitution that efforts were made to establish a general patent law. President Washington urged the enactment of such a law in his first Annual Address to Congress on January 8, 1790, when he said: "I cannot forbear intimating to you the expediency of giving effectual encouragement, as well to the introduction of new and useful inventions from abroad as to the exertion of skill and genius at home."

The bill which had been introduced in the previous year was enacted in amended form on April 10, 1790. At the time of this enactment Thomas Jefferson was Secretary of State and by virtue of his office became Keeper of Patents. It may be interesting to note that Mr. Jefferson was an inventor of repute. He is credited with having devised a swivel chair, a collapsible camp stool and a pedometer. He invented a machine for treating hemp and made an improvement in plows for which he received recognition abroad.

More than thirty years passed before The Franklin Institute was founded and it was two years more before THE FRANKLIN JOURNAL made its appearance under the editorial management of Dr. Thomas P. Jones. Dr. Jones, an Englishman by birth, American from choice, had a penchant for anything that related to inventions or patents and he was constantly alert for any material which might in any way refer to this subject. He carried on a spirited correspondence with Dr. William Thornton, first Superintendent of the Patent Office, who was appointed in 1802.

In the second issue of THE FRANKLIN JOURNAL, for February 1826, Dr. Jones devotes eight pages to a review of English patents which had only recently been granted. He also devotes some space to the activities of the French Patent Office.

The first mention of patents granted in the United States appears in the issue for May 1826. From this time on each issue contains data relating to recent patents, extracts from the claims, and criticisms by the editor. This data was supplied from time to time through the JOURNAL while Dr. Jones was editor and provides more information than is available in the early Patent Office records.

Claims of patents granted prior to the year 1843 were not published by the patent office but may be found in many instances in THE JOURNAL of the Institute.

In 1828 Dr. Jones was appointed Superintendent of the Patent Office suc-

ceeding Dr. William Thornton with whom he had frequently corresponded concerning patent law and patent practice.

After leaving Philadelphia, Dr. Jones continued the editorship of the JOURNAL and was elected its editor for life by the Board of Managers of the Institute.

In 1836 when the patent office was reorganized, a Commissioner of Patents was appointed and Dr. Jones was made one of the two Examiners. He served in this capacity until December 22, 1838, when he was compelled to retire. His interest in the Institute Journal was unabated and he continued to conduct its affairs from Washington. Dr. Jones died on March 11, 1848, and his work in behalf of American inventors was continued by others until 1859.

The Commitee on Science and the Arts of The Franklin Institute, appointed in 1824 and known then as the Committee on Inventions, has examined and reported upon more than 3100 inventions and discoveries. In each case it has based its report on the merits of the invention or device and in many instances has recommended an award or certificate.

The twenty-six exhibitions of American manufactures which were held annually and biennially under the auspices of the Institute from 1824 to 1858 did much to encourage invention and manufactures as may readily be discovered by referring to its many reports. Over 5000 exhibition "premium" awards were made.

The patent collections of the Institute's library include the complete specifications of the patents of Great Britain from the year 1617 to date; abridgments for the same period. The Commissioner of Patents Journal, 1854 to date, as well as the several index volumes.

The United States reports from 1790 to date, (abstracts to May 1871, complete specifications since that date); Official Gazette 1872 to date; Index volumes 1790 to date.

The French Patent Office is represented by the complete specifications from 1791 to July 1900 and the Bulletin Officiel de la Propriété Industrielle since 1938.

The German Patent-Blatt gives data from 1877 to date, in abstract; a trademark journal is also on file.

The Canadian Patent Office Record contains information about Canadian patents beginning in 1873.

The Swiss reports begin in 1888 and are still published; and the reports of Japan are on file since 1904.

The Australian Official Journal of Patents begins in 1904, and the Official Journal of Trade Marks in 1906.

There are abstract reports from the following countries: Austria, Austro-Hungary, Belgium, Finland, Hungary, New Zealand, Russia and Victoria, N. S. W.

ALFRED RIGLING, *Librarian.*

STATED MONTHLY MEETING, MARCH 20, 1940.

The regular monthly meeting was held this evening at 8.15 o'clock, Mr. W. Chattin Wetherill, Vice-president, in the chair.

The minutes of the previous meeting were approved as published in the March issue of the Journal.

The additions to membership since last report were as follows:

Active	8
Associate	20
Student	23
Total	51

On motion, duly seconded, Dr. Leo Hendrik Baekeland of New York and Dr. Arthur Holly Compton of Chicago, the Franklin Medalists of 1940, were unanimously elected to honorary membership in the Institute.

There being no further business the Chairman introduced Mr. Franklin Johnston, Editor and Publisher of the American Exporter, who addressed the meeting on "Export Trade and Domestic Prosperity." The speaker declared that the key to prosperity is export expansion. From the low point of 1932–33 world trade and American exports have improved steadily against difficult odds. The outbreak of the war has caused further stimulation to exports largely because of the elimination of German competition. The influence of the trade agreement program on our exports and domestic economy was outlined.

A spirited discussion followed the paper after which the Chairman conveyed the thanks of the meeting to Mr. Johnston.

Adjourned,

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday March 13, 1940.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 13, 1940.

DR. FREDERIC PALMER, JR., *in the Chair.*

The following reports were presented for final action:

No. 3041: Work of R. R. Williams on Vitamin B_1.

This report recommended the award of an Elliott Cresson Medal to Robert R. Williams, of New York City, N. Y., "In consideration of his researches upon vitamin B_1, including its isolation in the pure state in quantity sufficient for further chemical study, the identification of its segments, and its synthesis in quantity."

No. 3057: The Kodachrome Process.

This report recommended the award of Edward Longstreth Medals to Leopold Godowsky, Jr., and Leopold D. Mannes, of Rochester, N. Y., "In consideration of the ingenuity and inventive ability as shown in the development of Kodachrome Film and the processing thereof."

No. 3077: Levy Medal.

This report recommended the award of Louis Edward Levy Medals, jointly, to Charles Rosenblum and John F. Flagg for their paper entitled "Artificial Radioactive Indicators," which appeared in the October and November, 1939, issues of the Journal of The Franklin Institute.

No. 3078: Henderson Medal.

This report recommended the award of a George R. Henderson Medal to William E. Woodard, of New York City, N. Y., "In consideration of his accomplishments in locomotive engineering and his important contributions in the field of steam locomotive design."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 823 readers made use of the facilities during the twenty-four days of February.

RECENT ADDITIONS.

AERONAUTICS.

CARTER, C. C. Simple Aerodynamics and the Airplane. Fifth Edition. 1940.

ARCHITECTURE AND BUILDING.

American Society of Heating and Ventilating Engineers. Guide. Volume 18. 1940.

ASTRONOMY.

Aryabhata. The Aryabhatiya. An Ancient Indian Work on Mathematics and Astronomy. Translated with Notes by Walter Eugene Clark. 1930.

BIOGRAPHY.

FARRAND, MAX. Benjamin Franklin's Memoirs. 1936.
Who's Who. 1940.

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BALAREW, D. Der disperse Bau der festen Systeme. 1939.
HINTON, C. L. Fruit Pectins. 1940.
VOLMER, MAX. Kinetik der Phasenbildung. 1939.

ECONOMICS.

SMITH, EDGAR LAWRENCE. Tides in the Affairs of Men. 1939.

ELECTRICITY AND ELECTRICAL ENGINEERING.

BOUWERS, A. Elektrische Höchstspannungen. 1939.
FINK, DONALD G. Principles of Television Engineering. 1940.
MORGAN, ALFRED P. The Pageant of Electricity. 1939.
RIDER, JOHN F. The Oscillator at Work. 1940.

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BICK, A. F. Artistic Metalwork. 1940.
EVANS, MARY, AND ELLEN BEERS MCGOWAN. A Guide to Textiles. 1939.
GOTTSEGEN, JACK J. Tobacco. A Study of its Consumption in the United States. 1940.

MATHEMATICS.

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TSCHUPROW, A. A. Principles of the Mathematical Theory of Correlation. 1939.

MECHANICAL ENGINEERING.

COLVIN, FRED H., AND FRANK A. STANLEY. American Machinists' Handbook. Seventh Edition, Revised and Enlarged. 1940.

METALLURGY.

KINZEL, A. B., AND RUSSELL FRANKS. The Alloys of Iron and Chromium. Volume 2: High-Chromium Alloys. 1940.

METEOROLOGY.

LINKE, F., Meteorologisches Taschenbuch 5. 1939.

NAVAL ARCHITECTURE AND NAVIGATION.

BOWEN, FRANK C. The Sea: Its History and Romance. Four volumes. No date.

PHOTOGRAPHY.

MORGAN, WILLARD D., HENRY M. LESTER, AND OTHERS. Graphic Graflex Photography. 1940.
STENGER, ERICH. The History of Photography. Translation and Footnotes by Edward Epstean. 1939.

PHYSICS.

HERZBERG, GERHARD. Molecular Spectra and Molecular Structure. 1: Diatomic Molecules. 1939.

SCIENTIFIC ESSAYS.

Philadelphia College of Pharmacy and Science. Popular Science Talks. Volume 13. No date.
Royal Society of Edinburgh. Transactions. 1938–39. Volume 59, Part 3. 1939.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

SLOW MESONS IN THE COSMIC RADIATION.*

BY

C. G. MONTGOMERY, W. E. RAMSEY, D. B. COWIE AND D. D. MONTGOMERY.

The following experiment was performed to measure the disintegration time of cosmic-ray mesons. Mesons falling on a lead plate were detected by a layer of counters above the plate. Some of these mesons presumably stopped within the plate and a short time later emitted a disintegration electron and a neutrino. The electron would, in a certain fraction of the cases, be detected by a second layer of counters placed below the plate. Those events were recorded in which a discharge of one of the upper counters was followed by a discharge in one of the lower counters after a time t_1 and before a time t_2. In the absence of the lead plate, no disintegration electrons were expected. However, a considerable number of counter discharges were recorded which must be interpreted as the result of an intrinsic time delay in the counter between the passage of the ionizing ray, and an appreciable change in potential of the counter wire. The number of disintegration electrons was measured by taking the difference in the counting rates with the lead plate present and absent. For t_1 equal to 1.5 microseconds, and t_2 equal to 20 microseconds, we expected 23 electrons per hour, assuming that the mean life of the mesotron is 2.7 microseconds. A series of observations results in the measured number of 1.4 ± 2.4 per hour, a value much smaller than expected. Possible explanations of this discrepancy are discussed, the most likely one perhaps being that most mesons are absorbed by some nuclear process before they come to rest.

* An abstract of an article published in full in Phys. Rev., 56, 635 (1939).

THE UPWARD RADIATION PRODUCED BY COSMIC RAYS AT HIGH ALTITUDES.*

BY

S. A. KORFF AND E. T. CLARKE.

In order to investigate the effect of lead on the cosmic radiation at high altitudes, the following experiment was performed. A single Geiger counter was caused to occupy four positions relative to lead blocks. This was accomplished by mounting the counter on an arm which, when rotated by a small electric motor, carried the counter through a repeating cycle of four successive positions. The counts were scaled down and then transmitted by short wave radio to a station on the ground, by means of technique previously described. The counter walls were of such thickness that electrons below about 10^6 volts would not be counted. The position of the counter with respect to the lead was also transmitted, as were barometric and temperature data. The flight reached a minimum pressure of 23 mm Hg (approx. 80,000 ft.), and repeated the counting rate ratios on the descent, thus providing a check at corresponding pressures. The accuracy of the data is indicated by the standard deviations in column *A* of Table I.

TABLE I.

Counting rate in each of four positions with respect to lead as indicated in Fig. 1 as a function of pressure.

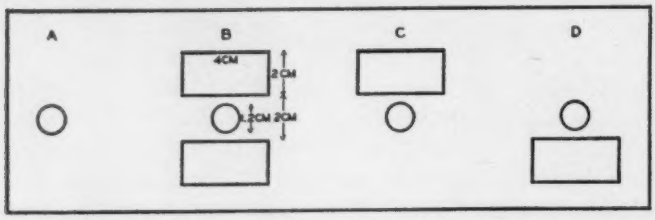
Pressure Interval (mm Hg)	*A*	*B*	*C*	*D*
23–100	10.0 ± 0.5	16.8	14.3	15.8
100–200	12.5 ± 0.5	13.6	13.1	13.0
200–400	4.7 ± 0.3	5.2	4.3	5.5
400–760	0.7 ± 0.2	0.8	0.8	0.7

The counter occupied the four different positions *A*, *B*, *C*, and *D* with respect to lead as shown in Fig. 1, and remained in each position for approximately one minute. The counting rates in each position are presented in Table I as a function of pressure. The counts were averaged for each position over four pressure intervals, and the average includes observations obtained on the down-flight as well as on the up-flight.

* Reprinted from Phys. Rev., 56, 704 (1939).

Let x equal the counting rate of the counter due to all the radiation incident upon it in the absence of lead (position A), p equal the transmission (combined absorption and shower production) coefficient for downward rays through the lead, z

FIG. 1.



Four positions of counter with respect to lead blocks during the flight.

the production coefficient of upward radiation produced by rays which impinge on the lead, and y the coefficient of production of upward radiation produced in the lower block of lead by rays which have passed through the upper block. Then the counting rates of the counter in the four positions A, B, C, and D will be given by $A = x$; $B = x(p + y + 1)$; $C = x(p + 1)$; $D = x(z + 1)$. Hence it follows that $(D/A) - 1 = z$; $(C/A) - 1 = p$; $(B - C)/A = y$, and thus we may determine the coefficients from the data. Further it follows that if $z = y$, $(C + D) = (B + A)$.†

TABLE II.

Shower production and absorption coefficient (p) and upward radiation production coefficients (z and y) derived from the observations.

Pressure Interval (mm Hg)	p	z	y
23–100	0.43	0.58	0.25
100–200	0.05	0.04	0.04
200–400	− 0.09	0.17	0.19

The values of the coefficients p, z, and y at the different altitudes are shown in Table II. It will be seen that p is

† This algebra assumes that the radiation is incident on the apparatus from the top hemisphere. If we assume that $x = x_1 + x_2$ where x_1 is incident radiation from above and x_2 from below, and since $z \leqslant 1$, then $(x_2/x) \leqslant 0.2$. For $z = 0.6$, $x_2 = 0$. Since z is presumably considerably less than 1, (x_2/x) appears to be a small quantity and is for the present neglected.

positive at high altitudes and becomes negative at low altitudes. This is in agreement with cascade theory, since at high altitudes many showers are produced in the lead, while at low altitudes more rays are absorbed than are added as showers. Further, A decreases rapidly with elevation at altitude above the maximum of the familiar cosmic-ray intensity-altitude curve, while B, C and D show no clearly marked maxima.

It will also be seen that at low altitudes z is almost exactly equal to y and the relation $(C + D) = (B + A)$ holds. At the high altitudes, however, z is considerably larger than y. The difference between z and y must be due to the screening by the upper block of the lower block in B, with the result that fewer upward ejections are produced in the lower block.

The observations indicate that the counting rate at the highest altitude in position D, with lead below the counter, is much greater than in position A with no lead present. Since it seems improbable that rays coming up from below would be of sufficient number or energy to produce such abundant upward showers in the lead block, it appears that ionizing radiation is ejected upward from the lead by downward directed rays. This effect is presumably due to reflection of electrons, to nuclear disintegrations, and to wide angle showers in the lead. A large effect due to reflection, which these observations indicate, suggests the presence of many electrons of low energy in the radiation at high altitudes.

These experiments were partially supported by the Carnegie Institution of Washington. Thanks are due also to W. F. G. Swann for helpful discussions and to Victor Legallais for construction of the apparatus.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Seminar on Rickettsial Diseases, led by DR. LUDWIK ANIGSTEIN.—On February 12, Dr. Anigstein favored the personnel of the Biochemical Research Foundation with a discussion of "The Problem of the Etiology of the Typhus Group of Diseases." Dr. Anigstein, who has held the post of Assistant Professor of Parasitology at the University of Warsaw, is a member of the Malaria Commission of the League of Nations, and is at present lecturer and research associate at the University of California, being delegated to the Department of Bacteriology at Columbia University.

The subject of typhus and its kindred diseases is no longer as simple as it appeared to be shortly after 1916 when the demonstration by Rocha-Lima, that typhus was caused by Rickettsia prowazeki, opened the door to further study. Widening knowledge has made it evident that typhus or typhus-like diseases occur almost everywhere between the polar circles. These diseases are found under widely varied climatic conditions and in very different racial and social elements of humanity. Moreover, while classical typhus has a clear clinical picture, strains of Rickettsiae vary from one locale to another, even when solely borne from man to man by the louse. The typhus-like diseases, carried by a variety of arthropod vectors, make the study even more complex.

All typhus-like fevers have certain features in common. Each is transmitted by an arthropod, and the portal of entry into man is always the skin. Infection may or may not be marked by a primary ulceration of the skin according to the type of disease. The body is covered more or less completely with a macular or papular rash. High fever appears suddenly at the onset of the disease, persists for 10 to 14 days, and as suddenly subsides. Death rates vary with local conditions and specific strains of Rickettsiae.

Dr. Anigstein reviewed the Rickettsial diseases as they exist over the world. In America we have representatives

of the two subgroups of typhus diseases—those carried by fleas and lice (Mexico), and those carried by ticks (United States). The Western and Eastern types of Rocky Mountain Spotted Fever are tick-borne, while Mexican Tabardillo and the murine typhus of the South are spread by fleas. The vector of Brill's disease, found in the eastern states, remains unknown.

South America has been the scene of great epidemics of louse-borne typhus, and a deadly tick-borne Rickettsial disease occurs in Sao Paulo.

The immensity of Asia with its wide range of climate and diversity of population makes it only natural that typhus should be found there in many forms. Studies in the Malayan peninsula have proved to be of special interest. Two distinct types exist there, quite different both epidemiologically and serologically. The rural form of typhus, found only in the fields and jungles, is probably carried by a larval mite. Serologically it corresponds to the Proteus XK, and is related to the Japanese River Fever, Tsutsugamushi. The urban form encountered in towns and villages is carried by a rat-flea, and corresponds to the Proteus X 19.

The human louse, which bears the classical typhus, is a stranger to the tropics. To find out whether this louse could be infected with tropical typhus, and to compare the tropical organism, if it appeared in the louse, with other cultures, Dr. Anigstein took two thousand lice to Malaya, feeding them himself enroute. Rickettsiae were found in abundance in lice inoculated by anal injection of infectious material or fed on patients with rural tropical typhus. The organism so obtained resembled *R. orientalis*, the cause of Tsutsugamushi. The investigations of other workers, subsequent to Dr. Anigstein's research, have proved the two organisms to be identical.

In Eastern Australia may be found the so-called "Mossman Fever," serologically the same as Tsutsugamushi. Another form of typhus, prevalent among the farmers to the south and west, is correlated with epizootics among field mice.

In Africa, as elsewhere, geographic and climatic factors which regulate the flora and fauna largely determine each particular type of vector. Murine typhus, louse-borne

typhus, and tick-borne typhus diseases are all found in favorable locations.

Europe has seen a new rise in typhus incidence since the decline of this disease at the close of the World War. Economic depression together with the gradual disappearance of immune individuals may account for this increase.

Certain problems of epidemiology remain of considerable interest. One is the question of how the typhus organism survives inter-epidemic periods. The pathology of the louse infected by *R. prowazeki* yields a picture of invasion of the epithelial cells of the intestine by the virus. Blunt swelling of the cell results, accompanied by the appearance of vacuoles and by flattening of the nucleus. The louse never survives more than 14 days. In spite of the fact that dead lice do not retain their infectiousness typhus continues to reappear after comparatively long periods of inactivity. One explanation has arisen from the observation that fecal material of lice may remain infective for guinea pigs as long as a year in the dry state at room temperature. Another important factor undoubtedly is the biological reservoir. This may take the form of susceptible animals, such as the rat, or may be human carriers with inapparent infections.

The murine typhus differs somewhat from the human type. The fact that the murine organism does not kill its host, the rat flea, has been interpreted as an indication that this disease is much older than the human, louse-borne disease, with profound adaptations between host and parasite having made them mutually compatible.

Beside *R. prowazeki*—always intracellular and discrete—other Rickettsiae are parasitic in lice. *R. rocha-limae* is an invasive organism which fills the epithelial cells of the louse in clumps. It causes distortion of the cells, but no vacuolization. The louse survives. Extra-cellular organisms may also be found, among which is the causative agent of Trench Fever—*R. quintanae*.

One of the most striking phenomena observed in the study of Rickettsial diseases is the Weil-Felix reaction. Certain strains of the Proteus organism agglutinate specifically with sera from typhus patients. These are known as the Proteus X strains. Proteus X 19 was isolated from the urine of a typhus

patient by Weil and Felix in 1916, and has proved of tremendous value in the diagnosis of classical typhus. Other strains of the X type have been useful in the diagnosis and correlation of the various other diseases of this group. Malayan rural and urban typhus can be distinguished, for example, by the fact that serum from patients with the former reacts with Proteus XK while serum from patients with the latter agglutinates X 19.

The problem of the relationship of Proteus X strains to the disease split the students of this subject into two camps for some time. One side argued that serological specificity, and the appearance of Proteus X in typhus patients, pointed to Proteus X as the true causative agent. The other side could not agree with this viewpoint since the Proteus X organisms could not be made to reproduce the disease experimentally. The conclusion has been drawn that Proteus X may represent a saprophytic form of the extremely pleomorphic and variable Rickettsia, occurring either as a part of the life cycle, or, more likely, as a result of sudden mutation.

The seminar closed with an interesting discussion of questions in connection with the use of sera and vaccines in therapy and prophylaxis.

(Reported by ROBERT K. JENNINGS.)

Effect of Solvation upon Molecular Weight Determinations by Means of Ultracentrifugal Methods.—ELMER O. KRAEMER. In a previous note (E. O. Kraemer, JOUR. FRANK. INST., **229**: 393 (1940)) (see also section on "The Partial Specific Volume Factor" by E. O. Kraemer in "The Ultracentrifuge," by Svedberg and Pedersen, Oxford University Press, London, 1940) a general equation was given, without derivation, showing the error that results in the determination of molecular weight by means of the ultracentrifuge when combination occurs between the macromolecular component and other components of the solution; such combination we shall for brevity call "solvation." This equation may be derived by suitable extension of the reasoning previously employed in discussing the analogous problem of solvation in a binary solution (Lansing and Kraemer, *J. Am. Chem. Soc.*, **58**: 1471 (1936)).

Consider a solution of volume v containing $x_1, x_2, x_3, x_4 \cdots x_k$ grams of components 1, 2, 3, 4, $\cdots$ and k, component 1 being the macromolecular material the molecular weight of which is sought. Whenever one gram of component 1 combines simultaneously with $r_2, r_3, r_4, \cdots$ and r_k grams of components 2, 3, 4, $\cdots$ and k, the composition of the solution becomes y_c grams of macromolecular-solvent compound, and $y_2, y_3, y_4, \cdots y_k$ grams of components 2, 3, 4, $\cdots$ and k, where

$$
\begin{aligned}
y_c &= (1 + r_2 + r_3 + r_4 + \cdots + r_k)x_1 = (1 + \Sigma r_i)x_1, \\
y_2 &= x_2 - r_2 x_1, \\
y_3 &= x_3 - r_3 x_1, \\
y_4 &= x_4 - r_4 x_1, \\
&\cdots \\
y_k &= x_k - r_k x_1.
\end{aligned} \tag{1}
$$

By definition, the partial specific volume V_i of component i is $\delta v/\delta x_i$, and since $v = f(y_c, y_2, y_3, y_4, \cdots y_k)$, the partial specific volume of component 1 (referred to the uncombined form) is given by the expression

$$
\begin{aligned}
V_1 = \frac{\delta v}{\delta x_1} &= \frac{\delta v}{\delta y_c} \cdot \frac{\delta y_c}{\delta x_1} + \frac{\delta v}{\delta y_2} \cdot \frac{\delta y_2}{\delta x_1} + \frac{\delta v}{\delta y_3} \cdot \frac{\delta y_3}{\delta x_1} \\
&\quad + \frac{\delta v}{\delta y_4} \cdot \frac{\delta y_4}{\delta x_1} \cdots + \frac{\delta v}{\delta y_k} \cdot \frac{\delta y_k}{\delta x_1} \\
&= \frac{\delta v}{\delta y_c}(1 + \Sigma r_i) + \frac{\delta v}{\delta y_2}(-r_2) + \frac{\delta v}{\delta y_3}(-r_3) \\
&\quad + \frac{\delta v}{\delta y_4}(-r_4) \cdots + \frac{\delta v}{\delta y_k}(-r_k).
\end{aligned} \tag{2}
$$

Similarly,

$$
\begin{aligned}
V_2 = \frac{\delta v}{\delta x_2} &= \frac{\delta v}{\delta y_c} \cdot \frac{\delta y_c}{\delta x_2} + \frac{\delta v}{\delta y_2} \cdot \frac{\delta y_2}{\delta x_2} + \frac{\delta v}{\delta y_3} \cdot \frac{\delta y_3}{\delta x_2} \\
&\quad + \frac{\delta v}{\delta y_4} \cdot \frac{\delta y_4}{\delta x_2} \cdots + \frac{\delta v}{\delta y_k} \cdot \frac{\delta y_k}{\delta x_2} \\
&= \frac{\delta v}{\delta y_c} \cdot 0 + \frac{\delta v}{\delta y_2} \cdot 1 + \frac{\delta v}{\delta y_3} \cdot 0 + \frac{\delta v}{\delta y_4} \cdot 0 \\
&\quad \cdots + \frac{\delta v}{\delta y_k} \cdot 0 = \frac{\delta v}{\delta y_2}.
\end{aligned} \tag{3}
$$

Likewise,

$$(4) \qquad V_3 = \frac{\delta v}{\delta y_3}; \qquad V_4 = \frac{\delta v}{\delta y_4}; \qquad V_k = \frac{\delta v}{\delta y_k};$$

and the partial specific volume V_c of the macromolecular compound c (including bound "solvent") equals $\delta v/\delta y_c$. Therefore, combining equations (2), (3), and (4), we obtain

$$(5) \quad V_1 = (1 + \Sigma r_i)V_c - r_2V_2 - r_3V_3 - r_4V_4 \cdots - r_kV_k$$

or

$$(6) \quad V_c = \frac{V_1 + \Sigma r_iV_i}{1 + \Sigma r_i} \qquad \text{(equation 2 of the previous note).}$$

Now the molecular weight M_c of the macromolecular *compound* is related to the molecular weight M_1 of the macromolecule in the free state by the expression

$$(7) \qquad M_c = (1 + \Sigma r_i)M_1.$$

On the other hand, the apparent molecular weight M_1^a obtained by the conventional calculation of either sedimentation equilibrium or sedimentation velocity plus diffusion data, using the partial specific volume of the uncombined macromolecule V_1, instead of V_c referring to the actual sedimenting particle, is related to the true molecular weight of the macromolecular *compound* M_c by the expression

$$(8) \qquad M_1^a(1 - V_1\rho) = M_c(1 - V_c\rho).$$

Combining equations (6), (7), and (8) and eliminating M_c and V_c gives

$$(9) \quad M_1 = M_1^a \frac{(1 - V_1\rho)}{(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)}$$

(equation 1 of the previous note).

The above derivations are all based upon the implicit assumptions that so-called Donnan effects are adequately repressed by suitable excess of neutral electrolyte, that the effects of compressibility are properly taken into account, and that the activity coefficient of the macromolecular solute is constant over the range of concentration involved in the experimental determinations.

For a binary solution, as shown by Lansing and Kraemer (*loc. cit.*), the equation corresponding to equation (9) is

$$M_1 = M_1^a \frac{(1 - V_1\rho)}{(1 - V_1\rho) + r(1 - V_0\rho)}. \tag{10}$$

By introduction of the definitions for partial specific volumes in terms of concentrations expressed as weight fractions, equation (10) reduces to

$$M_1 = M_1^a \frac{1 - w_1}{1 - w_1 - rw_1}, \tag{11}$$

where w_1 is the weight-fraction concentration of the uncombined macromolecular solute. It is thus evident that the error resulting from solvation in a binary solution is independent of the actual partial specific volumes of solute and solvent, and in any case is eliminated by extrapolation of the results to zero concentration. Even in concentrations as high as 0.5 per cent. ($w_1 = 0.005$), solvation to the extent of 400 per cent. ($r = 4$) leads to an error in molecular weight of only 2 per cent. Solvation therefore rarely if ever results in any appreciable error in determinations of molecular weights by ultracentrifugal methods when binary solutions are employed.

As a specific example of the errors that may arise in multicomponent solutions of the sort commonly used in the ultracentrifugal study of proteins, let us consider a 1 per cent. by weight solution of protein in 0.2 molar sodium chloride at 20° C. We have then

$$M_1 = M_1^a \frac{(0.991 - 0.750)}{(0.991 - 0.750) + r_{H_2O}(0.9911 - 1.0018) + r_{NaCl}(0.991 - 0.301)},$$

where 0.9911 is the specific volume of the protein solution; 1.0018, 0.750, and 0.301 are the partial specific volumes of water, protein and sodium chloride, respectively, in the given solution; and r_{H_2O} and r_{NaCl} are the grams of water and of sodium chloride, respectively, combined with one gram of protein. (Numerical values are taken from Svedberg and Pedersen, "The Ultracentrifuge.") After carrying out the

indicated operations, we obtain

$$M_1 = M_1^a \frac{0.241}{0.241 - 0.0107 r_{H_2O} + 0.69 r_{NaCl}}$$

$$= \frac{M_1^a}{1 - 0.044 r_{H_2O} + 2.86 r_{NaCl}}.$$

It is therefore evident that a hydration of 25 per cent. ($r_{H_2O} = 0.25$) would result in an error in molecular weight of only 1 per cent., whereas combination in equal degree with the salt would cause an error of 71 per cent. As a matter of fact, however, there is no evidence for any such combination of proteins with sodium chloride. In any case, it should be noted that for neither hydration nor combination of protein and salt can the error be eliminated by extrapolation of molecular weight values to zero protein concentration, in contrast to the situation for binary solutions.

Finally it is of interest to compare the above results with the corresponding effects in connection with osmotic pressure measurements. For a dilute (with respect to macromolecular solute) "ideal" solution, in which no combination occurs between solute and solvent molecules

$$M_1 = \frac{RT}{V_0 M_0 P} \cdot \frac{x_1}{n_0}, \tag{12}$$

where M_1 is the molecular weight of the homogeneous macromolecular solute, V_0 and M_0 are the specific volume and the molecular weight (or average molecular weight for a multicomponent solution), respectively, of the solvent, n_0 is the number of moles of solvent in the solution containing x_1 grams of the solute, and P is the osmotic pressure. Now assume that one gram of the solute combines with r grams of one or more components of the solvent; the weight of the solute becomes $x_1(1 + r)$, and its molecular weight similarly becomes $M_1(1 + r)$. Therefore, if the number of moles of free solvent is maintained constant, the osmotic pressure is unchanged; in other words

$$M_1(1 + r) = \frac{RT}{V_0 M_0 P} \cdot \frac{x_1(1 + r)}{n_0}, \tag{13}$$

and the correct molecular weight of the uncombined solute is obtained provided that n_0 represents the number of moles of *free* solvent. However, if n_0 is taken as equal to n_0', the total number of moles of solvent in the solution, and V_0 and M_0 are considered to refer to the solvent phase, an error results which may be expressed by the equation

$$M_1^a = \frac{RT}{V_0 M_0 P} \cdot \frac{x_1}{n_0'}, \tag{14}$$

where M_1^a is the apparent molecular weight obtained. Taking the ratio of equations (13) and (14)

$$\frac{M_1}{M_1^a} = \frac{n_0'}{n_0} \tag{15}$$

or

$$M_1 = M_1^a \frac{n_0'}{n_0} = M_1^a \frac{\text{total moles solvent}}{\text{moles free solvent}}.$$

In the usual case, the solution inside the osmometer is analyzed for the macromolecular solute, and the possibility that part of the solvent is combined with the solute is ignored in carrying out the calculations. If the weight of solute per gram of solution is w_1, the total weight of solvent is $1 - w_1$, and the weight of free solvent is $1 - w_1 - rw_1$. Therefore

$$M_1 = M_1^a \frac{1 - w_1}{1 - w_1 - rw_1}, \tag{16}$$

which is seen to be identical with the corresponding expression for the effect of solvation in a binary solution on molecular weights determined by ultracentrifugal methods.

In measuring the osmotic pressure of solutions containing one macromolecular solute in a mixed or multicomponent solvent, the proper procedure for obtaining well-defined osmotic pressures is first to equilibrate the solution by osmosis against several portions of solvent. This insures that the free solvent has the same composition in the solution as in the original solvent (even though combination may occur between the solute and one or more components of the solvent), and that the same values of V_0 and M_0 apply to solution and solvent phases. If then the solution in the osmometer at osmotic equilibrium is simply analyzed for

the solute, the considerations presented above in connection with equation (16) still hold, with r representing now Σr_i, the sum of the number of grams of the various components of the solvent combined with one gram of solute. However, it is generally only necessary to analyze the solution in the osmometer for each and every component (although in practise it may be difficult to do so with the desired accuracy), in order to detect that combination of solute and solvent has occurred, for combination with the various components usually does not take place in the same proportions as that in which they are present in the solvent phase. Unfortunately, such complete analysis of the solution can show only the differences in the amounts of the various solvent components combined with the solute, but not the absolute amounts, unless it is known, from other considerations, that one (or more) of the solvent components does not combine with the macromolecule; such a component may then be used as a so-called "reference substance." In the latter case, complete calculation of the results leads to detailed information concerning the composition of the macromolecule-solvent compound, as well as its molecular weight and the molecular weight of the uncombined solute. In the absence of a "reference substance" but with complete data on the difference in the compositions of the solvent and solution phases, suitable correction may be made for the combination between solute and a solvent component in so far as it occurs in proportions exceeding those in which the component in question exists in the solvent. However, there remains the possibility of a residual combination of all solvent components in the same proportions as they occur in the solvent phase. For this fraction of the combined solvent, it is unnecessary to distinguish the individual components, and the error in molecular weight becomes the same as that of a binary solution (equation (16)), where r refers to the grams of complete solvent combined with one gram of solute. In all cases, therefore, where the osmotic pressure is properly measured, solvation leads to the same form of error, whether the solution is binary or multicomponent.

Thus, it is seen that the effect of combination between solute and solvent components has the same effect on

molecular weights by ultracentrifugal and osmotic pressure methods for binary solutions, whereas for multicomponent solutions the effects, in general, are different. Only with osmotic pressure determinations is it possible, in principle, to eliminate the effect of solvation or other combination by extrapolation to zero concentration of macromolecular solute. It should be remembered, however, that in practise the ultracentrifugal methods possess many advantages over the osmotic pressure methods which more than compensate for this shortcoming, particularly the advantages of giving more accurate results at low concentrations where the "ideal" solution equations are valid, and of detecting molecular size heterogeneity in the macromolecular solute.

BOOK REVIEWS.

KINETIK DER PHASENBILDUNG, von Dr. Max Volmer. 220 pages, illustrations, tables, 16 × 23 cms. Leipzig, Theodor Steinkopff, 1939. Price 15 R.M.

The subject on which this book treats is under a continued observation of the closest character and the results of new discoveries are announced frequently in the technical press of the field nearest to the discoverer. It is a fact proven over and over again that such fundamental knowledge has widespread interest as for instance in meteorology, geology, biology, and in many technical and manufacturing processes. This book is of the class that presents a late picture of the theoretical considerations in the light of recent discoveries and conceptions.

First there is an introductory section giving a historical background and an underlying theory in preparation for that which follows. The treatment proceeds into a consideration of the single molecule during a change of phase, general theory of transgression, and a special treatment of the kinetics of changes in characteristic cases. The method and structure of lately discovered phases comprises the subject matter of the latter part of the book. Throughout the work care is given to provide ample proof of the developed theory and the treatment involves passages using only the statistical method of the classical thermodynamics.

The book contains many curves as illustrations of the text and developed formulas. There are also a subject and author index and an extensive bibliography. It is Volume IV of the series entitled "Die Chemische Reaktion."

R. H. OPPERMANN.

SCIENCE FOR THE WORLD OF TOMORROW, by Gerald Wendt. 316 pages, plates, illustrations, 14 × 21 cms. New York, W. W. Norton & Company, Inc. Price $2.75.

The title of this book suggest a broad coverage because the phrase "for the world of tomorrow" is indicative of a prediction of manners of life in the future and the position of science in the social world. It challenges thought along certain lines, which is valuable in contemplating any subject, especially this one. First off, it must be recognized that science has no existence of its own, but has grown out of and is dependent on industry. Conversely, industry now depends very largely on scientific development and progress. This is well illustrated by the amount of money devoted to scientific research—this in the face of the fact that, judged on the same basis as an industrial concern, science generally does not pay its way. It does undoubtedly provide the national income of the future and therefore is a decided national asset. Further than this, the savings produced by scientific effort in many cases are passed directly on to the user or consumer. It cannot be denied that science is an essential part of the social structure and if properly organized can lead to the general improvement of living conditions.

The author of this book trains his attack on this very objective. He defines science as the use of intelligence to improve the environment of human life, a

definition that may be either broad or narrow according to opinion. But definite limitations or borders are placed around the subject by further stating that the book examines the various aspects of life as a social phenomena brought to their present state by the progress of science and subject to further change from the same source.

Appropriately, the story begins with a picture of life in the age of science, a world different than any previous age has experienced with applications of science affecting every phase and every activity. Then inquiry is made into the natural resources of the earth and sky, and the resulting wealth according to man. Subsequently the advance in transportation is shown to affect life in "making the world grow smaller," likewise the effects of communications, construction, nourishment for the physical being, the prolonging of life, and the provision of clothing and personal raiment are all portrayed.

All of this discussion contains almost constant reference to social effects, particularly, of the material results of scientific achievements. It leads up to a climax in the latter part of the book when the more pointed problems of the day are covered, those of unemployment, war, and economic depression. Here, as in the earlier parts of the book, examination is made only in the light of scientific method and procedure. The answer to these and like problems is vague, yet definite. A study of human affairs without fear of words, traditions or force, seems the only solution in the eyes of the author. It is the function of interpreters of science and of teachers everywhere not merely to expound knowledge, not merely to praise the scientific method but to reveal the scientific attitude and to make its sources available to all, for the methods of science are applicable to larger human problems than they ever have been heretofore. The attitude of science expresses the highest reaches of the human spirit.

The author of the book is a man of considerable experience in many branches of scientific endeavor and is Director of Science of the New York World's Fair. The approach used is basically scientific, letting the cards fall where they may and stating facts as facts with little regard, in many places, to the fear of being misunderstood. This is not a drawback when the lay reader comes to realize that conclusions should not be hastily built through a clouded thought process. Written in a popular vein, the book is serious and informative without being burdensome reading.

R. H. OPPERMANN.

AUTOMATIC DESIGN OF CONTINUOUS FRAMES IN STEEL AND REINFORCED CONCRETE, by L. E. Grinter. 141 pages, illustrations, 15 × 24 cms. New York, The Macmillan Company, 1939. Price $3.00.

In the design of continuous frames, there is a great need for a procedure that is definite, accurate and a time saver. This is surprising when it is considered that in most engineering lines, "tools" in the way of methods and rules are worked out to be used in innumerable ways to accomplish a result. Often just a slight knowledge of the underlying principles of the "tool" is necessary for its use. But in this subject, it seems few such "tools" exist. The classical procedure, while of undoubted accuracy, consumes time and energy, things so vital when work of this nature is to be undertaken.

The author of this book offers a design process which he calls automatic, and which by-passes the tedious work of the classical methods, yet has several advantages over the "guess and check" method so often used. With relation to continuous beams it welds unorganized steps into a routine procedure of successive corrections, not unlike the Cross method of moment distribution, that will save a major part of the work involved in making design computations. The designer has opportunity to use his best judgment to speed the convergence but the automatic process claims good design irrespective of errors of judgement. Application of the process is here given to standardized structures, presenting solutions to the major problems. Continuous frames and haunched members are also given attention and in relation to the analysis of continuous frames by balancing angle changes, a suggested method is given of balancing fixed-end moments, that while it does not have advantages over the Cross method in the way of reduction of time consumed or in simplicity, it is practically self checking and at completion of the analysis all data necessary for sketching the deflected structure are at hand. It is particularly useful for studying secondary stresses in trusses and for investigating the effect of elastic distortion or of inelastic slip in the riveted or welded connections of a continuous steel frame. The last subject treated on is determining influence lines by balancing angle changes. Here there is combined in one procedure the convenience of the balancing process (performed upon angles instead of moments) and the refinement of the direct determination of the influence line from deflected structure.

The book provides a profitable study for those engaged in design work.

R. H. OPPERMANN.

FUNDAMENTAL PROCESSES OF ELECTRICAL DISCHARGE IN GASES, by Leonard B. Loeb. 717 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1939. Price $7.00.

It is often possible to trace, in the history of scientific activities, the progress of knowledge and developments resulting therefrom, and to quite definitely indicate crests of achievements as well as troughs or relative periods of inactivities and lesser accomplishments. When this can be done, the reasons for variations in activity can be assigned. The author of this book points out that the field of study of electrical discharge in gases developed with amazing rapidity from 1895 to about 1910 as a result of studies of one of the most able group of scientific investigators in a given field at one time. The peak of this work was reached when coordination and correlation of the studies of J. J. Thompson and J. S. Townsend brought forth the classics "The Conduction of Electricity Through Gases" and "Electricity in Gases." Then activity gradually subsided, due to rapid advance in other fields and the difficulty of overcoming drawbacks in existing techniques. At the present time, the reasons for inactivity having been gradually removed, revival in interest is taking place and activity is on the increase.

The two above mentioned classics have seen considerable use these many years. No other work has approached their popularity for they have been the standard and for a fact they have contributed largely to present studies as is evidenced by the references being made to them in the many recent papers in the periodical literature and society transactions the world over. This literature by its very nature cannot be a sumnation of existing knowledge. Therefore it

remains for a work such as this book to pick up the loose threads of literature, present the facts and conflicting views, and present opinions with regard to facts of importance, giving reasons.

This book is remarkable for its thoroughness of coverage. It opens with a treatment on ionic mobilities giving first a review of a few accurate and significant modern methods of measurement, then presenting in an orderly fashion results of studies of ionic mobilities with conclusions of the author, followed by a treatment of theory. The status of the subject recombination of ions is next treated which preceeds an interesting explanation of an elementary nature of the character of diffusion of ions. This leads to a discussion on the fundamental classical researches of Townsend and a survey of one or two problems showing qualitatively how ionic diffusion operates in a gas. The topic of measurements and theory of electron mobilities is covered historically, and furnishes a basis for the study of the complex concepts involved in energy distribution. Advances in the knowledge on the formation of negative ions goes into the use of newer apparatus and techniques as well as the presentation of later theories. These together with the treatment along lines of conduction currents in gases and the first and second Townsend coefficients, provide adequate prerequisites for the applications to problems of spark discharge, glow, and the arc to which the latter part of this book is devoted.

There is an enormous amount of data in the form of curves and tables. At the end of each chapter references are listed, the total amounting to a very large number, an indication of the exhaustive work in this phase alone. A comprehensive subject and author index is to be found in the back.

Without doubt the book is a useful tool to those interested in this subject, and as such is destined to give added impetus to activities in this and related fields.

R. H. OPPERMANN.

COSMIC RAYS, by R. A. Millikan. 134 pages, plates, illustrations, 14 × 21 cms. New York, The Macmillan Company, 1939. Price $2.50.

Cosmic rays seem to be a popular subject from one end of the country to the other. Perhaps the reason for this is that it has stirred the imagination, not so much from the standpoint of its immediate value in resulting material things or its value from the standpoint of increased knowledge, as from conceptions of the vague invisible forces and tremendous space dimensions involved. Popularity in this sense leads to light conversation which while of little scientific import, is a favorable reaction never-the-less. Even such a wide popular manifestation in Galileo's time would have given greater impetus to the search for truth. It also indicates that interest now penetrates further than the immediate necessities and conditions of life.

This book on cosmic rays is divided into three papers or lectures, they being the revision of the 1936 Page-Barbour Lectures of the University of Virginia and the 1937 John Joly Lectures of Trinity College, Dublin. The first of these entitled "The Discovery of Cosmic Rays and Its General Significance" is an exposition of directness of presentation. Instead of taking the statement "its general significance" the author makes it more direct by endeavoring to answer the question "What are cosmic rays good for?" The answers, drawn from experience of the past, are very interesting. One of them is given emphasis to a considerable degree

although its value relates purely to society. It is the scientific mode of approach to new knowledge and new avenues of progress—this, the result of a study of science underlying the discovery of cosmic rays. The scientific ideas that came into human thinking through the development of the telescope and the microscope undoubtedly had much to do with the shaking off of the shackles of both religious and political authoritarianism and the establishment of religious, intellectual and political freedom. This paper is one that can be read with profit by almost everyone of average intelligence, and it admirably brings the lofty so-called pure scientific knowledge right down to a practical basis in-so-far as a social value is concerned.

The other two papers on "Superpower Particles" and "The Earth's Magnetic Field and Cosmic-Ray Energies" relate in detail the stages by which the present position in knowledge has been reached, giving accounts of the experimental methods used, illustrated with many cloud chamber photographs as well as with diagrams, tables, and photographs of apparatus. To follow these of course requires a prerequisite of a general scientific training. Both of them take the form somewhat of a narrative which is exceptional in that not only facts and conditions are set forth during the various stages of progress but the direction of future work is indicated, by references to gaps in knowledge revealed, the need for proofs, etc.

The work is an outstanding account of the method employed in this great discovery.

R. H. OPPERMANN.

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA. Cumulative Index, Volumes 1–10. New York, American Institute of Physics. Price $3.00.

After ten years the Society has published what will prove to be a most valuable key to its *Journal*.

It gives a classed list of subjects to which reference is made in the Index. This is followed by a cumulative author index and then, in turn, comes an analytic index. This latter is divided into twelve subdivisions. An author index of contemporary literature on acoustics, as listed in the *Journal*, makes references to all articles which have appeared, in any publication, between April 1937 and April 1939; this is followed by an analytic subject index covering data above referred to. The Index will make the volumes of the *Journal* still more useful.

PUBLICATIONS RECEIVED.

The Tools of the Chemist, Their Ancestry and American Evolution, by Ernest Child. 220 pages, plates, illustrations, 16 × 22 cms. New York, Reinhold Publishing Corporation, 1940. Price $3.50.

Properties of Ordinary Water-Substance, by N. Ernest Dorsey. 673 pages, illustrations, tables, 16 × 24 cms. New York, Reinhold Publishing Corp., 1940. Price $15.00.

The Journal of the Acoustical Society of America, Cumulative Index, Volumes 1–10. 131 pages, 20 × 27 cms. New York, American Institute of Physics. Price $3.00.

Mechanics of Liquids, An Elementary Text in Hydraulics and Fluid Mechanics, by Ralph W. Powell. 271 pages, illustrations, tables, 16 × 24 cms. New York, The Macmillan Company, 1940. Price $3.50.

Proceedings of the Seventh Summer Conference on Spectroscopy and its Applications, held at the Massachusetts Institute of Technology, Cambridge, Mass., July 17–19, 1939. 154 pages, illustrations, tables, 19 × 25 cms. New York, John Wiley & Sons, Inc., 1940. Price $2.75.

Reflexion et Refraction des Ondes Seismiques Progressives, par L. Cagniard. 255 pages, illustrations, 17 × 25 cms. Paris, Gauthier-Villars, 1939. Price 120 fr.

Electrochemistry and Electrochemical Analysis, by Henry J. S. Sand. Volume I, Electrochemical Theory. 133 pages, illustrations, 13 × 19 cms. London, Blackie and Son Limited. 4 × 6d.

The Ultracentrifuge, by The. Svedberg and Kai O. Pedersen. 478 pages, plates, illustrations, tables, 17 × 25 cms. Oxford, Clarendon Press, 1940. Price $12.50.

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